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IN THE

Supreme Court of the United States

OCTOBER TERM, [redacted]1969

No. [redacted]251

MAGNETIC HEATING CORPORATION, THERMATOOL CORPORATION, DAVID G. OSTERER, HERMAN C. MORRIS, AMERICAN MACHINE & FOUNDRY COMPANY,

Petitioners,

v.

JULIUS E. FOSTER,

Respondent.

PETITION FOR A WRIT OF CERTIORARI TO THE UNITED STATES COURT OF APPEALS FOR THE SECOND CIRCUIT

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June 17, 1969

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Petitioners, Magnetic Heating Corporation, Thermatool Corporation, David G. Osterer, Herman C. Morris, and American Machine & Foundry Company (hereinafter usually referred to as petitioners or as AMF) respectfully pray that a writ of certiorari issue to review the judgment of the United States Court of Appeals for the Second Circuit entered in this case on March 20, 1969, holding Foster patent No. 2,882,384 valid and infringed.

THE OPINIONS BELOW

The opinion of the United States District Court for the Southern District of New York is reported at 297 F. Supp.

512. It is printed in petitioners' Appendix* at pages 1a-15a.

The *per curiam* opinion of the Court of Appeals for the Second Circuit is reported at F. 2d and at 161 USPQ 133. It is printed in petitioners' Appendix at page 16a.

JURISDICTION

The judgment of the Court of Appeals was entered on March 20, 1969 (App. p. 17a). The jurisdiction of this Court is invoked under 28 U. S. C. Section 1254(1). The District Court's jurisdiction is founded on 28 U. S. C. Section 1338(a).

QUESTION PRESENTED

Is the public interest in freedom from unwarranted monopolies served by invoking the equitable doctrine of "equivalents" to justify enlargement of the term and scope of an unused ("paper") patent when

(1) as a result of the patentee's deliberate delay the patent in suit issued seventeen years after it should have, during which time petitioners had independently developed their allegedly infringing system,

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*The Appendix contains, in addition to the opinions below, Pls. Ex. PX-1 (the Foster patent in suit); Pls. Ex. PX-2 and PX-3 (Patents Nos. 2,833,910 and 2,818,488, showing petitioners' apparatus); and Defts. Ex. DX-C—Tab 4 (Patent No. 2,139,211, showing the Sessions prior art structure).

For convenience, reference, where possible, will be to the Appendix (cited "App. p.").

Italics and brackets within quotations are ours unless the contrary is noted.

(2) the established legal principles announced in the controlling decisions of this Court preclude such expansion of the patentee's monopoly?

STATEMENT OF THE CASE

This patent infringement action, commenced in 1965, was tried in June 1968. In August 1968 the District Court, adopting virtually verbatim plaintiff's proposed findings of fact and conclusions of law, and without filing a separate opinion, held the Foster patent valid and infringed (App. pp. 1a-15a). The Court of Appeals affirmed *per curiam* nine days after argument, on the basis of the District Court "opinion" (App. p. 16a).

Plaintiff, Foster, is a patent attorney in private practice. His patent relates to a conventional welding process of a type which came into wide use in the early 1920's. The monopoly spawned by it had a markedly unusual genesis and history.

The original application on which the Foster patent is based was filed in December 1939 and allowed by the Patent Office December 8, 1941 (Defts. Ex. DX-A, 2d unnumbered page). In ordinary course, Foster's patent would have expired seventeen years after its issuance, thus ending his statutorily authorized monopoly. Foster's putative monopoly did not terminate at the end of this seventeen year period, however, because he deliberately elected to forfeit the monopoly to which his patent would have entitled him at that time. On December 23, 1953, twelve years after his first application for a patent monopoly was allowed and abandoned, Foster filed a new application, virtually duplicating the patent which he had previously turned down by failing to pay the final Patent Office fee, and which, on April 14, 1959, issued as the patent in suit (Pls. Ex. PX-1, App. pp. 18a-38a).

The Foster patent describes and claims a process and apparatus for continuously forming and welding tube or pipe, using ordinary household low frequency current—one which alternates 60 cycles per second (Pls. Ex. PX-1, col. 10, lines 43-47, App. p. 30a; col. 1, lines 69-70, App. p. 26a).

The tube or pipe is made by drawing a flat strip from a coil and passing it between a succession of rollers which bend the strip into a lengthwise, cylindrical shape, with its two edges abutting. The approaching strip edges form a V, with its apex at the point of initial contact between the edges. A pair of roller electrodes are in contact with the edges of the cylindrically formed strip adjacent to and on each side of the seam at the apex of the V. The electric current passing through the electrodes and thence across the abutting edges of the tube raises the temperature of these edges so that they become hot enough to melt or flow together, producing a continuous weld along the seam (Pls. Ex. PX-1, col. 7, lines 8-75, App. p. 29a; col. 9, line 17 through col. 10, line 7, App. p. 30a).

In all of these respects, the Foster patent describes welding systems which were old and well known when Foster filed his first patent application (Defts. Ex. DX-C—Tabs 1 and 2). The patent represents, however, that these earlier systems resulted in a seam having welded "spots", separated by unwelded segments, and Foster aimed to cure this by a single innovative step. Specifically, the Foster patent proposes to eliminate the spots by spreading out or "scanning" the weld current along the seam. To accomplish this, Foster contributed the idea of using a special electromagnet which, according to the patent, develops and establishes an alternating magnetic flux field to move the weld current through a predetermined path (Pls. Ex. PX-1, col. 4, lines 17-31, line 56 through col. 5, line 6, App. pp. 27a-28a; col. 10, line 57 through col. 11, line 7, App. pp. 30a-31a; col. 11,

lines 19-61, App. p. 31a; col. 13, lines 3-34, App. p. 32a; col. 14, lines 54 through col. 15, line 2, App. pp. 32a-33a). Foster's electromagnet, positioned perpendicularly to the weld seam, is connected to a source of alternating current, the frequency of which is a multiple of—preferably three times higher (i.e., 180 cycles per second) than—the frequency of the weld current stream (*id.*, col. 13, lines 26-30, App. p. 32a; col. 14, lines 35-74, App. p. 32a; col 4, line 69 through col. 5, line 6, App. pp. 27a-28a; col. 11, lines 19-42, App. p. 31a).

The invention of the Foster patent has never been made, or used, or sold, and no license has ever been granted for rights under it (Tr. p. 122; Foster Dep. pp. 96-98, 102-104).

During the period 1951-1952, after Foster had abandoned his first application for a patent monopoly and before he had filed his second application, petitioners designed equipment which generated large quantities of high frequency electric power. In 1953 and 1954, this high frequency generator was used in developing petitioners' high frequency welding system. In 1955, four years before the Foster patent in suit issued, the first commercial installation of petitioners' high frequency welding system was completed (Tr. pp. 164-175).

Unlike the low frequency (60 cycles per second) system of the patent in suit, petitioners' system operates at very high frequencies, employing current which alternates in the neighborhood of 400,000-500,000 cycles per second. This high frequency current is applied to two small, rectangular electrodes, or contacts (Pls. Ex. PX-2, 16 and 17 of Fig. 1, App. p. 39a), each of which rides on one of the open edges of the tube to be welded, a few inches in advance of the apex of the V. (Pls. Ex. PX-3, col. 6, lines 54-60, App. p. 48a). The heating effect of this high fre-

quency current, concentrated on the surfaces of the edges, causes them to become hot enough to be welded as they are forced together (Pls. Ex. PX-3, col. 2, lines 45-52, App. p. 46a).

Welding systems known and used before Foster's first patent application shared with petitioners' system an undesirable charactertistic known as "back current." A "back current" is a current which runs, not as it should, from electrode, across the welding seam, to electrode, but instead from electrode, circumferentially around the back of the tube being worked on, to electrode. This "back current" does not contribute to the welding function and therefore is wasted (Tr. pp. 159-162). To avoid this waste, petitioners use a "core" element, described and used for this identical purpose in the expired Sessions patent (*infra*, pp. 13-14).

The Foster patent issued April 14, 1959, four years after petitioners had gone into commercial production. Six years later Foster commenced this action.

ARGUMENT

1. The Decisions Below Are in Conflict With Applicable Decisions of this Court and Run Counter to the Overriding Public Policy Favoring Free Competition

Reduced to their essentials, the decisions below have (1) sanctioned an improper prolongation of Foster's patent monopoly, (2) unduly expanded the scope of the monopoly of a "paper" patent, and (3) included within Foster's patent monopoly prior art features specifically relinquished by Foster during prosecution of his applications in the Patent Office, and subsequently used by petitioners in their welding system.

These results inevitably followed because the lower courts improperly applied to the facts here the doctrine of

equivalents, an equitable doctrine developed by the courts to protect deserving inventors and to discourage unscrupulous infringers. In arriving at this destination, the courts below disregarded significant teachings of this Court in patent cases, placing themselves in square conflict with applicable decisions of this Court and with the fundamental policy of restricting patent monopolies to their proper and legal scope.

The keystone for the holding of infringement by the lower courts was that:

> "The Foster magnet and the defendants' core are functional equivalents" (App. p. 9a).

The doctrine of equivalents is a judicial gloss on the law of patent infringement which, in appropriate cases, is invoked to delineate and to expand the scope of what appears on the surface to be a less extensive patent monopoly. The rationale on which the doctrine is founded was spelled out by the majority opinion of this Court in *Graver Mfg. Co.* v. *Linde,* 339 U. S. 605 (1950):

> "But courts have also recognized that to permit imitation of a patented invention which does not copy every literal detail would be to convert the protection of the patent grant into a hollow and useless thing. Such a limitation would leave room for—indeed encourage—the unscrupulous copyist to make unimportant and insubstantial changes and substitutions in the patent which, though adding nothing, would be enough to take the copied matter outside the claim, and hence outside the reach of law. One who seeks to pirate an invention, like one who seeks to pirate a copyrighted book or play, may be expected to introduce minor variations to conceal and shelter the piracy. Outright and forthright duplication is a dull and very rare type of infringement.

> To prohibit no other would place the inventor at the mercy of verbalism and would be subordinating substance to form. It would deprive him of the benefit of his invention and would foster concealment rather than disclosure of inventions, which is one of the primary purposes of the patent system. (339 U. S. 607)
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> * * *
>
> "The essence of the doctrine is that one may not practice a fraud on a patent. Originating almost a century ago in the case of *Winans* v. *Denmead,* 15 How. 330, it has been consistently applied by this Court and the lower federal courts, and continues today ready and available for utilization when the proper circumstances for its application arise. 'To temper unsparing logic and prevent an infringer from stealing the benefit of an invention' a patentee may invoke this doctrine to proceed against the producer of a device 'if it performs substantially the same function in substantially the same way to obtain the same result'." (339 U. S. 608)

The opinion in *Linde* makes it clear that the doctrine of equivalents is one which is available and should be utilized only "when the proper circumstances for its application arise."

As we will develop, the "circumstances" here are not "proper" for its application. Equitable considerations, which undoubtedly influenced the Court in *Linde,* are absent here, and furthermore, application of the doctrine of equivalents here is categorically denied by legal principles enunciated in a long line of authorities. These authorities foreclose invocation of the doctrine to preclude an "infringer" from practicing the prior art, or to permit a patentee to recoup a monopoly which he has surrendered in the Patent Office.

Extending to Foster the benefit of the doctrine of equivalents in the circumstances of this case is a drastic departure from established law and from sound public policy.

The opinion of the Court in *Linde* alludes (339 U. S. 612) to the fact that defendants there had not offered any evidence that their infringing composition was developed by independent research, from which it was inferrable that the infringement was the result of imitation of the patented composition. That circumstance does not obtain here. Petitioners' welding system was developed independently of any knowledge about Foster or of his abandoned patent application (maintained in secrecy by the Patent Office), and petitioners' system was commercialized before Foster's invention was made public by the issuance of his patent. Additionally, and also unlike the facts in *Linde*, petitioners' system includes new features concededly not part of Foster's patent. Moreover, petitioners' system differs in consequential respects from the system described and claimed in the Foster patent.*

Foster's unconscionable delay in securing his patent monopoly is a further equitable consideration to be taken

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*The District Court's holding of infringement was based on a fancied equivalence between the electromagnet of the Foster patent and petitioners' magnetic core. In reaching this holding, the District Court misconceived the teachings of the Foster patent as well as the operation of petitioners' system:

1. The District Court misunderstood the operation and the function of the electromagnet of the Foster patent. Petitioners' core is an "insulation material" and a "non-electrical conductor," the sole function of which is to "impede" or inhibit "back current." It is not electrically actuated, it does not establish a magnetic flux field of the type described in the Foster patent, and it does not move the weld current through the predetermined path of the Foster patent.

2. The District Court misapprehended the patent's restriction to a low frequency welding system, and it failed to appreciate the patent's further teaching that the use of a high frequency current in such an environment was an impossibility.

into account in deciding whether the circumstances here are appropriate for invoking in Foster's favor the doctrine of equivalents. If Foster had accepted his statutory monopoly when it was first offered to him, his patent would have issued sometime in 1942 and its seventeen year term would have expired in 1959, leaving the public (including petitioners) free to use everything which the patent had previously covered. Instead, Foster deliberately delayed, ultimately obtaining a patent whose seventeen year monopoly began (instead of ended) in 1959, and will expire in 1976. Such conduct should not be rewarded by application of an equitable doctrine which puts Foster in a position to exact tribute from the technological advances made by AMF during the early 1950's.

In making available to Foster the equitable doctrine of equivalents, the decisions below are manifestly incompatible with the basic policies expounded by this Court many years ago in *Woodbridge v. United States,* 263 U. S. 50 (1923):

> "Congress relies for the public benefit to be derived from the invention during the monopoly on the natural motive for gain in the patentee to exploit his invention and to make, use and vend it or its products or to permit others to do so, for profit. The importance in working out the purpose of Congress of keeping the inventor's monopoly within the term for which the patent is granted is thus shown to be capital. Any practice by the inventor and applicant for a patent through which he deliberately and without excuse postpones beyond the date of the actual invention, the beginning of the term of his monopoly, and thus puts off the free public enjoyment of the useful invention, is an evasion of the statute and defeats its benevolent aim" (263 U. S. 55-56).

In *Woodbridge*, this Court held that the patentee had forfeited his right to obtain a patent because he had deliberately delayed its issuance for a period of nine and a half years. The lower courts' application of the doctrine of equivalents here is inconsonant with the policy of prompt disclosure endorsed by this Court in *Woodbridge*, and also in *Linde*.

Foster's intentional delay in obtaining his narrowly defined patent monopoly disqualifies him from invoking an equitable doctrine fashioned to benefit those who would otherwise have been cheated out of what was rightfully theirs. And this is especially so when the ambit of Foster's monopoly is enlarged by application of this doctrine to encompass petitioners' developments made independently of, and in ignorance of, Foster's subsequent patent.

Also persuasive with respect to the equities here is the circumstance that the Foster patent has never been used. It is properly characterized as a "paper" patent, and progress in the welding art should not be restrained by broadening its scope in any respect. Instead, the patent should be strictly construed, limiting Foster's monopoly to the invention described and claimed in it, *Thompson* v. *Westinghouse Electric & Mfg. Co.*, 116 F. 2d 422, 425 (2 Cir. 1940).

The patent statutes require that each patent specification "shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the applicant regards as his invention" (35 U. S. C. § 112). The equitable doctrine of equivalents is properly called into play when the burden on the patentee to define his invention, in accordance with the statutory requirements, is so unfair as to warrant some form of extraordinary relief. No such burden is present here. Foster's invention was not difficult to define, and Foster, a patent attorney, had two separate chances to define it.

Confining Foster's patent monopoly to what he described and claimed in his patent would not have worked any undue hardship on, and would not have been unfair to, Foster. The undue hardship here is placed squarely on petitioners because of the application below, in plainly improper circumstances, of the doctrine of equivalents to embrace within Foster's low frequency monopoly petitioners' independently developed high frequency system.

In applying the doctrine of equivalents to the facts in this case, the lower courts have demonstrated that the dissenting opinions in *Linde* were not concerned with mere strawmen. The decisions below derogate from the salutary purpose, referred to in Mr. Justice Black's dissent, of "protect[ing] businessmen from retroactive infringement suits and judicial expansion of a monopoly sphere beyond that which a patent expressly authorizes" (339 U. S. 615). Indeed, the decisions of the lower courts here fulfill the dissent's prediction that:

> "The Court's ruling today sets the stage for more patent "fraud" and "piracy" against business than could be expected from faithful observance of the congressionally enacted plan to protect business against judicial expansion of precise patent claims. Hereafter a manufacturer cannot rely on what the language of a patent claims. He must be able, at the peril of heavy infringement damages, to forecast how far a court relatively unversed in a particular technological field will expand the claim's language after considering the testimony of technical experts in that field. To burden business enterprise on the assumption that men possess such a prescience bodes ill for the kind of competitive economy that is our professed goal." (339 U. S. 617)

The decisions here sought to be reviewed demonstrate the perspicacity of the observation in *Borg-Warner Corporation* v. *Paragon Gear Works, Inc.*, 355 F. 2d 400 (1 Cir. 1965) that:

> "Carried to an extreme, the doctrine of equivalents could undermine the entire patent system." (355 F. 2d 404)

2. The Doctrine of Equivalents Cannot Deprive Petitioners of the Right to Practice the Process of an Expired Patent Without Payment of Tribute to Foster

The Sessions patent expired December 6, 1955, and its teaching of the use of a horizontal, cyclindrical core in a continuous welding system, for the purpose of minimizing "back current," then became public property.

Petitioners have used such a core for such a purpose in such a system.

The lower courts, in applying the rule of equivalents, and thus denying to petitioners the right to practice the process of the expired Sessions patent, brought their decisions into conflict with the rationale of *Scott Paper Co.* v. *Marcalus Co.*, 326 U. S. 249 (1945).

In the *Scott Paper* case, this Court stated that:

> "By the force of the patent laws not only is the invention of a patent dedicated to the public upon its expiration, but the public thereby becomes entitled to share in the good will which the patentee has built up in the patented article or product through the enjoyment of his patent monopoly. . . .
>
> "It is thus apparent that the patent laws preclude the patentee of an expired patent and all others including petitioner from recapturing any part of the former patent monopoly; for those laws dedicate to all the public the ideas and inventions embodied in an expired patent" (326 U. S. 256).

In *Scott,* this Court refused to sanction an attempt to thwart a basic aim of the limited monopoly authorized by the patent laws, namely dedication "to all the public the ideas and inventions embodied in an expired patent." This basic aim of the patent system applies with equal force to the case at bar. Curtailing the right of petitioners, or any other segment of the public, to practice the teaching of the expired Sessions patent by the application of equivalents is antithetical to the policy underlying our patent system, and proscribed by recognized legal principles.

Mr. Justice Clark, writing for the Court in *Graham* v. *John Deere Co.,* 383 U. S. 1 (1966), correctly observed:

> "Moreover, Congress may not authorize the issuance of patents whose effects are to remove existent knowledge from the public domain, or to restrict free access to materials already available." (383 U. S. 6)

A fortiori, "free access to materials already available" should not be restricted by application of the judicial doctrine of equivalents.

3. Where the Patentee Has Narrowed a Claim During Prosecution of His Application in the Patent Office the Doctrine of Equivalents Cannot be Used to Recapture the Broader Coverage Which Was Surrendered

In arriving at their holdings of infringement, the Courts below ignored the fact that the history of the prosecution of Foster's patent applications had made the doctrine of equivalents unavailable to Foster as a matter of established law. During prosecution of his patent applications Foster had drawn such a distinction between the Foster electromagnet and a core like petitioners' core as to preclude infringement by petitioners' system. In so holding, the

courts below brought themselves into square conflict with this Court's decisions in *Weber Elec. Co.* v. *Freeman Elec. Co.*, 256 U. S. 668, 677-678 (1921); *I. T. S. Co.* v. *Essex Co.*, 272 U. S. 429, 443-445 (1926); *Smith* v. *Magic City Club*, 282 U. S. 784, 790 (1931); *Schriber Co.* v. *Cleveland Trust Co.*, 311 U. S. 211, 217-222 (1940); *Exhibit Supply Co.* v. *Ace Corp.*, 315 U. S. 126, 136-137 (1942); and *Graham* v. *John Deere Co.*, 383 U. S. 1, 33 (1966).

This Court's recent statement in the *Graham* case accurately summarizes the applicable rule:

> "Claims as allowed must be read and interpreted with reference to rejected ones and to the state of the prior art; and claims that have been narrowed in order to obtain the issuance of a patent by distinguishing the prior art cannot be sustained to cover that which was previously by limitation eliminated from the patent" (383 U. S. 33).

The corollary to the rule—that a file wrapper estoppel precludes resort to the rule of equivalents—was applied in the *Weber* case, 256 U. S. 677-678; the *I. T. S.* case, 272 U. S. 444; the *Smith* case, 282 U. S. 790; and the *Schriber* case, 311 U. S. 221. It is summed up in the *Exhibit Supply* case:

> "Whatever may be the appropriate scope and application of the doctrine of equivalents, where a claim is allowed without a restrictive amendment, it has long been settled that recourse may not be had to that doctrine to recapture claims which the patentee has surrendered by amendment" (315 U. S. 136).

The facts here which close the door to the doctrine of equivalents are clear and positive.

The Foster patent claims, as originally filed, and from which the claims in suit ultimately emerged, had broadly provided for causing the welding current "to reciprocate along the engaging traveling seam edges," or "shifting" that current through "a path of predetermined pattern," or through a "predetermined path" (Original Claims 3, 7, 12 and 15; Defts. Ex. DX-A, pp. 52-56).

These claims were rejected by the Patent Office Examiner as not defining anything which was not already described in the earlier Sessions patent 2,139,211 (Defts. Ex. DX-C—Tab 4, App. pp. 51a-66a) and in other cited prior art references (Defts. Ex. DX-A, pp. 68-69, 81, 94-95).

The Sessions patent is directed to a conventional tube forming and low frequency electric resistance welding system, including a horizontal cylindrical core, positioned within the tube being formed. (Defts. Ex. DX-C—Tab 4, p. 4, col. 1, lines 53-65, App. p. 58a and Figs. 4-24, App. p. 51a). The purpose of this core was to minimize the wasted "back current" (*id.*, p. 3, col. 2, lines 12-25, App. p. 57a; p. 4, col. 1, lines 66-71, App. p. 58a).

To distinguish his invention from the Sessions patent, the Foster patent claims were limited by amendment to require a specific magnetic flux control field, created by a specifically described and specifically disposed electromagnet. (Defts. Ex. DX-A, pp. 70, 71, 74, 82-83, 111-112).

Foster differentiated his magnetic flux control field from the magnetic core of the Sessions patent, representing to the Patent Office that Sessions:

> "does not direct attention to the same problem as the present application does [and] . . . does not show a system that would solve the present problem" (*id.*, p. 87).

Eventually, and on the basis of this and similar representations, the claims in the Foster patent were allowed (*id.*, p. 94; Defts. Ex. DX-B, pp. 85, 94, 102).

The lower courts erred in not applying the controlling rule of the cases cited *supra* at page 15.* Had those Courts applied the proper and universally recognized rule, they could not have avoided holding that petitioners' core, like the Sessions core, designed, as even Foster admits, to reduce "back current" (Foster Dep. pp. 199-203), was disclaimed by Foster in the Patent Office, and that the doctrine of equivalents was no longer available as a predicate for infringement.

CONCLUSION

The decisions of the lower courts, because of their unwarranted application of the doctrine of equivalents, will retard rather than advance the Constitutional purpose of promoting the progress of science and the useful arts. They run counter to the philosophy of the patent system and to the public interest in free competition, both of which ap-

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*In affirming *per curiam* the District Court's judgment without independently considering the file wrapper, the Court of Appeals for the Second Circuit put itself out of step with the Court of Appeals for the First Circuit. That Court adopted the proper approach in reversing a holding of infringement in the recent case of *General Instrument Corporation* v. *Hughes Aircraft Co.*, 399 F. 2d 373 (1 Cir. 1968):

> "A reviewing court—and a trial court—must therefore scrutinize the Patent Office proceedings with as much care as it does the disclosures and claims in the patent itself. Moreover, what is at issue is not merely a contest between the parties but a public interest that cancelled or rejected claims not be revived and restored. *Schriber Co.* v. *Cleveland Trust Co.*, supra at 221, 61 S. Ct. 235. We therefore, as in the past, feel bound to review the file wrapper history even though not ventilated in the District Court [citing cases.]" (399 F. 2d 385-386)

propriately restrict the limits of patent monopolies to inventions clearly described and distinctly claimed.

The writ should issue so that the limits of doctrine of equivalents may be clearly defined, as well as to correct the excesses reflected in the opinions below and to guard against their repetition.

Respectfully submitted,

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June 17, 1969

Opinion of the United States District Court for the Southern District of New York, 297 F. Supp. 512 (August 23, 1968)

[2] PALMIERI, J.

Preliminary Statement

This is a patent infringement case. The patent in suit relates to the progressive continuous welding of metals. It can be used effectively with such items as sheet metal tubes.

The essential issues raised by the pleadings are whether or not this patent was infringed by any of the defendants and whether it should be held invalid for abandonment or enforceable for laches. In the earlier stages of these proceedings the defendants relied upon defenses to the effect that the patent in suit was invalid because it was not novel in view of the prior art within the meaning of 35 U. S. C. § 102; and additionally, because the invention would have been obvious to those skilled in the art within the meaning of 35 U. S. C. § 103. These defenses were waived at the trial. The sole ground on which the defendants have attacked the validity of the plaintiff's patent is that the same is allegedly inoperative.

Claims of abandonment and laches were the basis for a motion by the defendants for summary judgment, Fed. R. Civ. P. 56, in the pretrial stages of the case. This motion was withdrawn after argument in the light of the Court's suggestion that the issues could be appropriately decided only by trial. The papers submitted [3] on the motion for summary judgment were by stipulation incorporated as part of the trial record.

The plaintiff patent owner and inventor, Julius E. Foster, is a patent solicitor by profession, possessing a scientific and technological background in electrical engineering and metallurgy.

For the reasons which are to be found in the findings of fact and conclusions of law which follow, this patent is held to be valid, and infringed, and plaintiff has sufficiently demonstrated his entitlement to relief.

FINDINGS OF FACT

The Parties

1. The plaintiff Julius E. Foster is a citizen of the United States residing in the Bronx, New York, and, at all times material herein, has been the owner of the patent in suit. Mr. Foster was formally trained in electrical engineering and has studied metallurgy. He has had considerable experimental and theoretical experience particularly in the field of welding and metallurgy, both from the engineering aspects and from his experience as a patent attorney, first with the Westinghouse Company and then more recently in private practice. He has made other inventions than the patent in suit in the field of welding [4] and in other fields, and has received patents thereon; with emphasis upon his engineering activities as distinguished from his patent law activities.

2. Defendant Magnetic Heating Corporation and defendant Thermatool Corporation are New York corporations having addresses for service of process at New Rochelle, New York.

3. Defendant David Osterer (hereinafter referred to as "Osterer") is a citizen of the United States residing in Harrison, New York; and defendant Herman C. Morris (hereinafter referred to as "Morris") is a citizen of the United States, residing in Scarsdale, New York.

4. New Rochelle Thermatool Corporation, originally incorporated under the name New Rochelle Tool Company, was doing business in New Rochelle, New York, which included the development, manfacture, sale, lease and licensing of high frequency welding equipment until in or about February 1962, when it was merged into defendant Magnetic Heating Corporation. The two individual defendants, Osterer and Morris, together with other individuals not named in this suit, Wallace C. Rudd presently a vice-president of defendants (hereinafter referred to as "Rudd") and Robert J. Stanton (hereinafter referred to as "Stanton"), were equal beneficial owners of all of the outstanding stock in defendants Magnetic Heating Corporation and Thermatool [5] Corporation, and in a corporation not named in this suit, New Rochelle Thermatool Corporation (hereinafter collectively referred to as "Thermatool").

5. Defendant American Machine & Foundry Company (hereinafter referred to as "AMF") is a New Jersey corporation with a principal office and place of business in New York, New York. On February 16, 1962, AMF acquired substantially all of the business and assets of Thermatool upon issuance of shares of AMF stock and the assumption by AMF of all liabilities and performances of all obligations, with certain specified exceptions, of Thermatool. Thereafter, the business was conducted entirely by AMF through its wholly owned subsidiary AMF Thermatool, Inc.

6. The defendant AMF has assumed responsibility for the defense of this infringement suit and for the [5a] payment of any judgment that may be entered against any of the defendants based upon the infringement charge.

The Patent in Suit

7. The Foster patent in suit is United States patent No. 2,882,384, entitled "Welding System". It relates to the progressive continuous welding of such items as sheet metals tubes with the aid of a pair of electrodes to which is applied an alternating current voltage for the purpose of supplying electric current for heating the edges of the tube to weld the same together in a continuous process as the sheet metal is folded into tubular form and drawn past the electrodes.

[6] **The Prior Art and the Teachings of the Patent in Suit**

8. Welding apparatus of this character had long preceded the Foster invention, since at least the early 1920's, but was subject to spotty heating effects that produced discontinuous welding spots or beads which left the welded tube with spaced unwelded regions and stress-concentration weakened zones, which prohibited the use of such tubes in applications where they were required to pass fluids or the like or where they were to be pressurized.

9. This problem of "spotty" welding was sought to be solved over the years by numerous proposals, including: (A) lowering the speed of drawing of the tube past the electrodes, which greatly limited production speeds and still did not provide absolutely continuous welds; (B) producing overlapping weld spots which again restricted the speed of formation of the welded tube, produced stress concentrations, and still left unwelded areas along the seams adjacent to the overlapped weld spots or beads; (C) varying the pressure of the pressing of the tube seam together during

welding to increase the heating effect at the electrodes which, again, placed limitations on speed of formation and produced discontinuous welds despite such control; and (D) increasing the frequency of the alternating current applied to the electrodes to higher frequencies, [7] which step by itself alone did not prove to effect high speed continuous welds.

10. It remained for Foster to conceive a radically new idea in alternating current welding that, as subsequently proven by the experience of defendants, and as correctly taught and predicted in the Foster patent, remarkably solved this longstanding welding problem that the art had tried such numerous methods of solving without substantial success. That revolutionary concept resided in preventing the alternating current applied to the electrodes contacting the seam edges of the tube to be welded, from just flowing transversely in the paths between the electrodes, and in forcing the same rather "to sweep or reciprocate the current stream back and forth through a space of predetermined length in the seam, thereby to cause the welding current stream to establish a welding action longitudinally along the seam, instead of making the spaced spot welds as in the prior practice" (Col. 4 of the Foster patent, line 64, on). By this forcing of the transverse current to flow longitudinally along the seam edges in front of the electrodes, the heating is not just confined to the opposite points at the electrodes, but there is effected a heat weld of a predetermined longitudinally portion of the seam edges that provides for a continuous and not a localized heated spot weld or bead.

[8] 11. The apparatus by which Foster proposed to effect this forcing of the current, that would normally other-

wise pass along transverse paths between the electrodes, so that it would move longitudinally along the V seam edges being joined and welded, was a magnetic core structure disposed within the tube being welded and disposed adjacent to the electrodes and the surfaces being welded, to set up an alternating magnetic flux field at the welding region adjacent to the welding current stream and, in the words of, for example, method claims 16 and 22 and apparatus claim 19 of the Foster patent, perpendicular or at right angles to the current stream to cause the same "to move" or "reciprocate" longitudinally along the seam edges in the region where they are becoming "progressively engaged". In the embodiment of Foster's Fig. 34, for example, the magnet 71 with its pole pieces pointing upward, and properly physically and angularly positioned with respect to the region of the electrodes and the V-shaped progressively engaged welding zone at seam 66, is disclosed for producing this effect.

12. While Foster illustrates a properly positioned and angularly oriented electromagnetic device 71 in his Fig. 34, the use of an electromagnet is clearly stated in the patent to be only "by way of example" (Col. 11, line 21); Foster interchangeably uses both the [9] term "electromagnetic" and just "magnet" throughout the patent (Col. 11, lines 21 and 22, lines 26 and 33, for example); and the art at this time had long recognized that magnetic flux could be produced both by directly exciting a magnet, as an electromagnet, and by inductively exciting a magnet from an external current, and that magnetic control of currents is identically affected by magnetic flux whether such flux is produced by a directly excited electromagnet or by an induced magnet core.

13. Method claim 5 describes the invention similarly to method claim 16, except that it is somewhat broader in merely specifying the setting up of the alternating flux control that is "disposed physically and angularly relative to the current stream to establish an electro-dynamic action between the control flux field and the flux field of the weld current to cause the current stream to reciprocate longitudinally of the seam in the region of the progressive contact".

14. While the Foster patent teaches that the use of higher frequencies alone cannot, in Foster's view, solve the continuous speed welding problem in and of itself, the patent does teach that when used with the proper internal magnetic core, properly positioned and oriented as above described, the Foster invention is useful with "multiple" or "higher frequency control".

[10] **The Validity of the Foster Patent**

15. The evidence upon which the defendants claim that the patent in suit is inoperative is the testimony of defendants' Vice-President Rudd. His testimony has been largely rejected by the Court because it was inconsistent in important particulars and lacked persuasiveness. Rudd's testimony was, in essence, that he did not think that the Foster device would work as described for reasons which rested upon statements in certain textbooks which he originally testified he himself had found.

16. On cross-examination, however, Mr. Rudd (a) conceded that the textbook statements did not in fact deal with the Foster patent equipment and operation, and, indeed, that it was others and not he who even found the textbook

references, and he was not even able to interpret or explain those references to the Court; (b) conceded that though he and AMF could have made a test of the actual operativeness of the Foster patent system they deliberately did not do so; (c) ultimately conceded that the Foster system of Fig. 34 would operate after all, just as described, contrary to his testimony on direct examination; and (d) in fact, at an earlier date, before this litigation, Rudd demonstrated a thorough appreciation of the operativeness of the use of the appropriate magnetic core to attain the desired results at both 60 cycles per second and at high radio frequencies, in his disclosure to his patent attorney of what he then thought was his own invention.

[11] **The Patent in Suit Has Been Infringed by the Defendants**

17. The defendants have manufactured and sold products similar to those disclosed in Figs. 1 through 4 of the Rudd and Stanton patent 2,833,910 and in Fig. 5 of Stanton and Rudd patent 2,818,488, within six years of the commencement of this action in the United States.

18. Each of the welding structures of Figs. 1 through 4 of patent 2,833,910 and 2,818,488, Plaintiff's Exs. 2 and 3, respectively, when operated in their intended manners, embodies every one of the method steps of Foster claims 5, 16 and 22 and the complete combination of elements set forth in Foster's apparatus claim 19.

19. The testimony of plaintiff Foster and the defendants' witness Rudd, and the statements of the Rudd and Stanton patents 2,818,488 and 2,833,910, Plaintiff's Exs. 2 and 3, all clearly show that the defendants' structures oper-

ate in substantially the same manner with substantially the same elements to attain the same results as described and claimed in the Foster patent in suit.

20. Though the magnet core employed in the defendants' structures is an induced magnet core, it produces the alternating magnetic flux required by the Foster claims to move the electric current longitudinally up and down the edges of the seam where they are being [12] progressively engaged to produce Foster's claimed result in substantially the same way as does the illustrated Foster electromagnet core. The Foster magnet and the defendants' core are functional equivalents.

21. Further, though there my be additional advantages in the use of defendants' high radio frequencies; insofar as the Foster invention is concerned and the desirable results attained by his appropriately positioned angularly oriented magnetic core, the defendants' structures must and do utilize this invention to attain the very advantages sought and taught by the Foster patent.

22. While defendants have called attention to the Sessions patent 2,139,211, Defendants' Ex. C, for the sole purpose of indicating that defendants are not using the Foster invention, but are using something closer to the Sessions invention, it should be observed that the Patent Office allowed the Foster claims in full knowledge of this very Sessions patent (Col. 26, line 50 of Foster patent) so that the Foster claims were on their face granted for something over and above Sessions' invention. Since defendants' apparatus finds response in the Foster claims, such apparatus obviously embodies more than the Sessions patent discloses; particularly since the defendants concede that what Foster has

patented "cannot be found in the prior art or held to be obvious in view of it" (page 7 [13] of defendants' trial brief). As stated in the file wrapper of the Foster patent when the Examiner originally cited the Sessions patent, all that the particular type of core and its orientation could produce in the device of the Sessions patent was, in Foster's words

> "preventing or reducing the by-pass current that flows around the back of the tube instead of across the seam, directly between the electrodes.
>
> "Nowhere in the Sessions patent is there any suggestion of any appreciation of the problem and the solution which are treated in this application." (File Wrapper, p. 87, Defendants' Ex. A)

The Examiner agreed that this is all that the Sessions patent teaches and allowed claims for the Foster concept of forcing the otherwise transverse current to move longitudinally down the edges being progressively engaged for welding; and, as above stated, this is precisely what the type of core and its orientation and excitation achieves in the defendants' structures.

23. The advantages attained by the defendants' apparatus that are stressed in their literature are precisely those taught in the Foster patent: higher speed, elimination of spots and discontinuities, provision of continuous progressive weld with fine grain structure, no lines or regions of stress concentration, flexibility for use with both thin and thick metal pipes of different [14] dimensions, and concentration of the welding current in the longitudinal edge region being joined.

There Has Been No Forfeiture or Abandonment. Laches Has Not Been Proved.

24. Foster filed a first application, Serial No. 311,557 for his invention on December 29, 1939, obtained allowance on December 8, 1941, and refrained from paying the final fee, whereupon that application became abandoned.

25. At the time he refrained from paying the final fee, Foster was in the employ of the United States Army Signal Corps during war time. While he appreciated the revolutionary nature of his invention, he was concerned about the adequacy of his application in terms of protecting the same. He had not at that time acquired either an electrical engineering degree or sufficient specialized technical information "to ascertain the correctness of the invention and its full scope and to educate [himself] to the extent that would enable [him] to ensure that all possible modifications and equivalents of this invention had been technically and properly covered in the application." In short, what he described as the "worth" or merit of the application, in this technical sense, was not then established; and though he tried to get information and assistance from military sources, he failed in this and concluded that he had "to go [15] back to college and learn about design principles" for himself to insure this "correctness", "full scope" and proper coverage in the application. Foster acted in good faith and it is for this reason alone that he did not pay the final fee. Foster has given credible testimony that "never, at any time did I abandon, or intend to abandon, the invention"; and "that there was nothing deliberate in my failure to pay final fee insofar as delaying the benefit of the invention to the public may be concerned. Further, there was no thought whatso-

ever to abandon my efforts to obtain proper patent protection for the said invention."

26. In accordance with his above-expressed intentions, Foster "thereupon immediately enrolled in the electrical engineering course in the evening school of George Washington University, in Washington, D. C., and continued there through 1945", transferring to the evening school in the engineering department of Polytechnic Institute in Brooklyn upon his transfer to New York through 1950, returning to George Washington University to receive his electrical engineering degree in 1951, and then continuing his graduate electrical engineering studies at the graduate school of the Polytechnic Institute until he obtained that "greatly deepened and widened insight into the operating problems in welding" that gave him the conviction [16] he could file a new application for patent (Serial No. 399,942, filed December 23, 1953, which matured into the patent in suit) with the assurance that "all possible modifications and equivalents of this invention had been technically and properly covered".

27. A comparison of the first application and the second application demonstrates the additional claiming and greatly revised claims that this educational program had equipped Foster to effect.

28. The attention of the Commissioner of Patents was directed by Foster to the earlier application (in which the final fee had not been paid) when filing the later and second application. The Commissioner of Patents ruled that under the law and rules and regulations, the new application was legally proper and maintainable, and the Commissioner assigned the same a serial number, and permitted the old application patent drawings to be used in the new case to save Foster expense.

29. In assigning a serial number, the Commissioner, acting under the law and rules, however, restricted Foster to the filing date of his new application, with the result that Foster, in the new examination of his new application, was made to assume the risk of another inventor having made his invention in the interim, a contingency which had it occurred, would have defeated Foster's patent. The new [17] examination revealed no intervening invention, and the patent issued with the new claims.

30. The earliest and uncorroborated date of disclosure by any of the defendants of a control core in a two-electrode alternating current welding system is March 3, 1954, several months after the filing date of the new application of Foster that matured into the patent in suit; and there is no evidence of any intervening invention by defendants or by others of such a combination before this Foster filing date.

31. There is no evidence that defendants or any of them relied on any delay by Foster or were lulled into any position to their prejudice, or materially changed their position as a result of any reliance upon any acts or omissions of Foster that could possibly give rise to the application of the doctrine of laches.

Conclusions of Law

1. This Court has jurisdiction of the parties and of the subject matter of this action. 28 C. S. C. § 1338(a). Jurdiction over the parties and subject matter and venue are not in controversy.

2. Plaintiff, Julius E, Foster, is the owner of United States Patent No. 2,882,384.

3. United States Patent No. 2,882,384 is good [18] and valid in law; and defendants have not sustained the burden

of proving this issued patent to be invalid for alleged inoperativeness. *Technical Tape Corp.* v. *Minnesota Mining & Mfg. Co.*, 143 F. Supp. 429, 437-8, *aff'd* 247 F. 2d 343 (2d Cir. 1957).

4. The Commissioner of Patents in accepting the new application that matured into the patent in suit and in ultimately issuing such patent, correctly ruled that there had been no abandonment or forfeiture, deliberate or otherwise, and that there were no intervening rights invalidating the same attendant upon Foster's failure to pay the final fee of the earlier application. 35 U. S. C. § 102; *Gallagher and Weber* v. *Smith*, 206 F. 2d 939 (Court of Customs and Patent Appeals, 1953).

The following cases relied upon by defendants are distinguishable and inapplicable to the facts hereinabove set forth:

Woodbridge v. *United States*, 263 U. S. 50, 56 (1923);

Wirebounds Patents Co. v. *Saranac Automatic Mach. Corp.*, 65 F. 2d 904 (6th Cir. 1933);

Allison Mfg. Co. v. *Ideal Filter Co.*, 21 F. 2d 22 (8th Cir. 1927);

Metallizing Engineer Co. v. *Kenyon Bearing & A.P. Co.*, 153 F. 2d 516, 520 (2d Cir. 1946).

5. Defendants have not proved abandonment, forfeiture or the existence of intervening rights. To the [19] contrary, plaintiff has adduced sufficient and persuasive evidence of the lack of same.

6. The defendants' Thermatool apparatus of the type simliar to that shown and described in Fig. 5 of Rudd and Stanton Patent No. 2,818,488 and in Figs. 1-4 of Stanton

and Rudd Patent No. 2,833,910 infringes each of claims 5, 16, 19 and 22 of Foster Patent No. 2,882,384.

7. It is not a prerequisite for a patent that its disclosure must have been built and operated; and where the patentee is not in the business, failure to spend large sums is not the proper basis for describing the patent as a "paper patent", particularly where it involves a revolutionary new concept. *Baxter Laboratories, Inc.* v. *Corn Products Co.*, 157 U. S. P. Q. 482 (7th Cir. 1968).

8. Even if narrowly construed, however, each and every step and element of Foster claims 5, 16, 19 and 22 finds response in terms, function and result in the defendants' Thermatool apparatus.

9. Plaintiff is not barred by laches from maintaining this suit. Mere delay in bringing suit is not a sufficient basis for the invocation of this equitable doctrine.

10. Plaintiff is entitled to injunctive relief restraining the defendants, their agents, employees, and others under their control, from continuing the infringement of plaintiff's patent No. 2,882,384.

[20] 11. Plaintiff is entitled to an accounting to determine the damages by reason of defendants' infringement.

12. Plaintiff is entitled to costs and expenditures.

Submit proposed judgment on notice.

Dated: New York, N. Y.
August 23, 1968

/s/ Edmund L. Palmieri
EDMUND L. PALMIERI
U. S. D. J.

Opinion of the United States Court of Appeals for the Second Circuit, 161 USPQ 133, F. 2d (March 20, 1969)

Before MOORE, KAUFMAN and FEINBERG, Circuit Judges.

PER CURIAM:

This is an appeal from an interlocutory judgment of the United States District Court for the Southern District of New York, Edmund L. Palmieri, J., holding certain claims of Patent No. 2,882,384, issued to plaintiff Julius E. Foster valid and infringed by American Machine & Foundry Company and other named defendants. On appeal, defendants do not contest the validity and enforceability of the patent and raise only the issue whether they infringed. We have considered the briefs and arguments in this court and see no basis for disturbing Judge Palmieri's findings of fact and conclusions of law relating to infringement. On that issue, we affirm on the basis of his careful opinion.
F. Supp.

Judgment affirmed.

Judgment of the United States Court of Appeals for the Second Circuit (March 20, 1969)

This cause came on to be heard on the transcript of record from the United States District Court for the Southern District of New York, and was argued by counsel.

ON CONSIDERATION WHEREOF, it is now hereby ordered, adjudged and decreed that the interlocutory judgment of said District Court be and it hereby is affirmed with costs to be taxed against the appellants.

Plaintiff's Exhibit PX-1

April 14, 1959 J. E. FOSTER 2,882,384

WELDING SYSTEM

Filed Dec. 23, 1953 8 Sheets-Sheet 1

Fig. 1

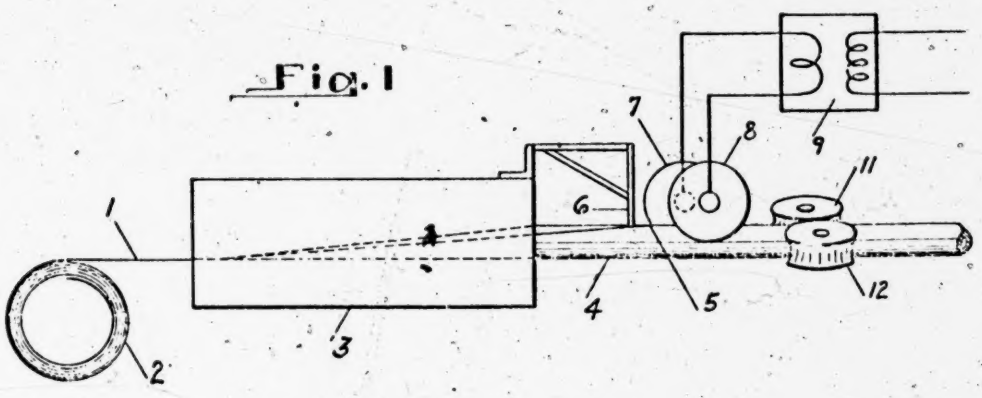


Fig. 2

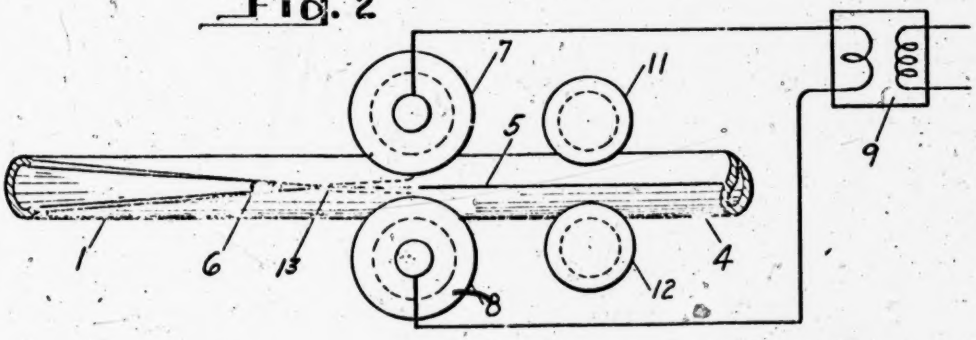


Fig. 6

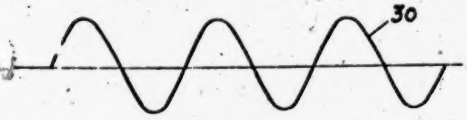


Fig. 7

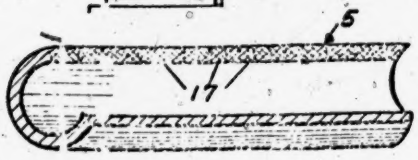


Fig. 3

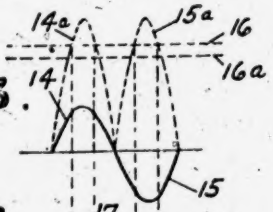
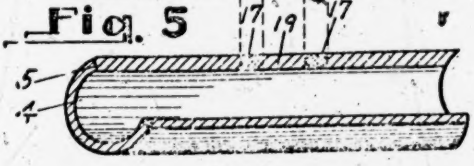


Fig. 4

Fig. 5



INVENTOR.

BY Julius E. Foster

ATTORNEY

Plaintiff's Exhibit PX-1

April 14, 1959 J. E. FOSTER 2,882,384

WELDING SYSTEM

Filed Dec. 23, 1953 8 Sheets-Sheet 2

Fig. 8

Fig. 9

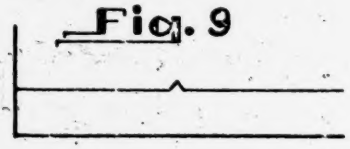


Fig. 10

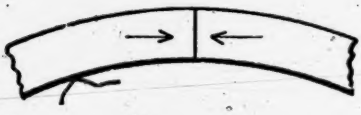


Fig. 11

Fig. 12

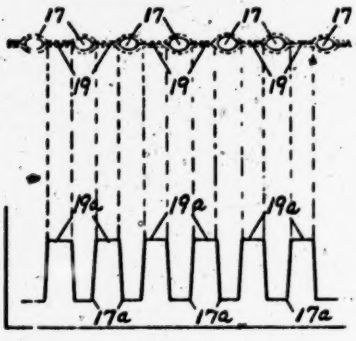


Fig. 13

Fig. 14

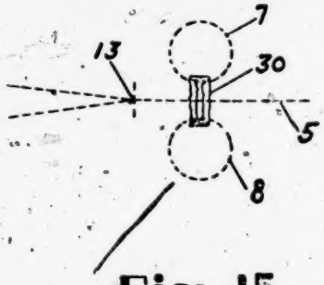


Fig. 15

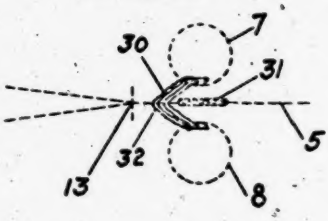
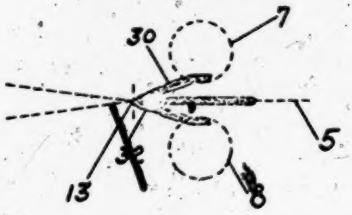


Fig. 16



INVENTOR.

BY Julius E. Foster

ATTORNEY

Plaintiff's Exhibit PX-1

April 14, 1959 J. E. FOSTER 2,882,384

WELDING SYSTEM

Filed Dec. 23, 1953 8 Sheets-Sheet 3

Fig. 17

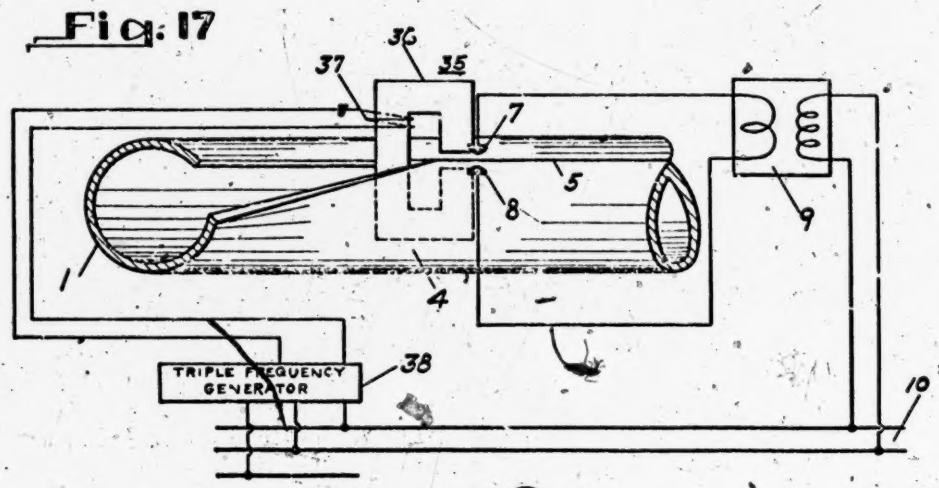
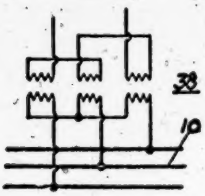


Fig. 17A



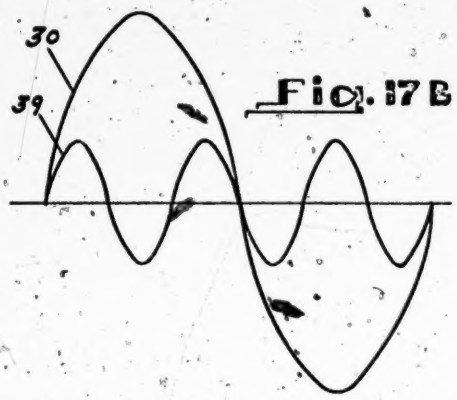
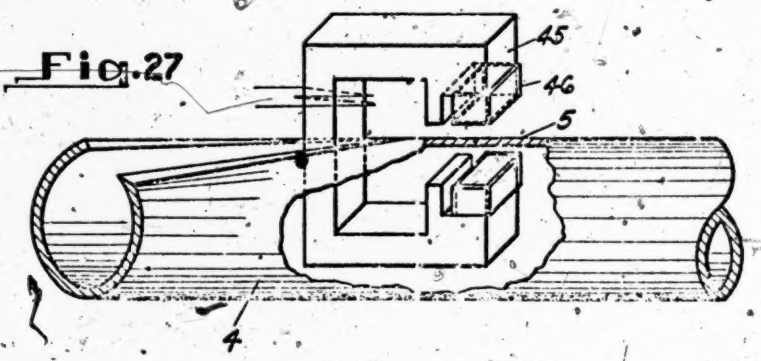


Fig. 17B

Fig. 27



INVENTOR.

BY

ATTORNEY.

Plaintiff's Exhibit PX-1

April 14, 1959 J. E. FOSTER 2,882,384

WELDING SYSTEM

Filed Dec. 23, 1953 8 Sheets-Sheet 4

Fig. 18

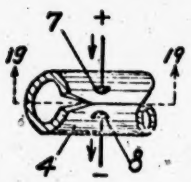


Fig. 19

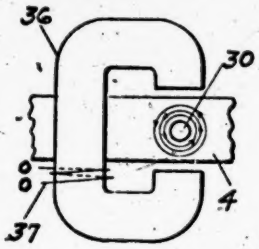


Fig. 20

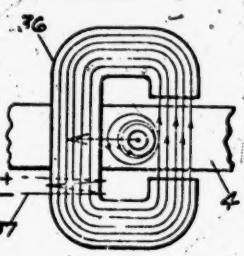
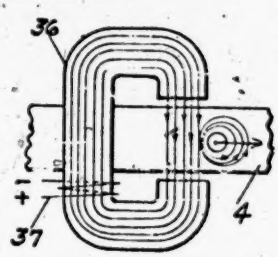
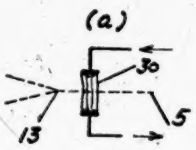
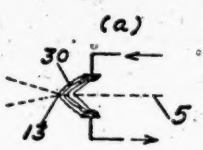
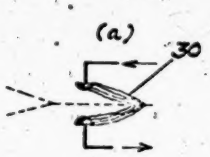


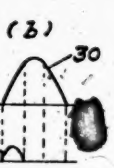
Fig. 21











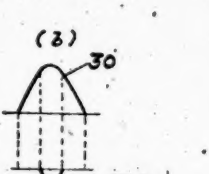


Fig. 22

Fig. 23

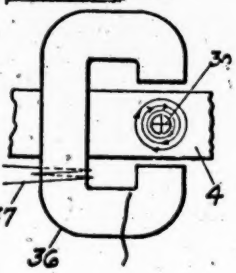


Fig. 24

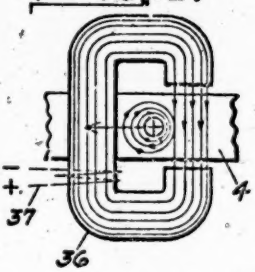
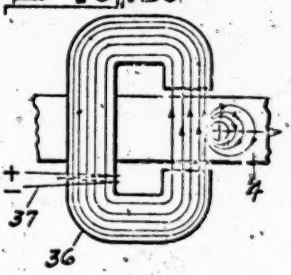
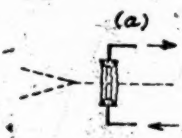
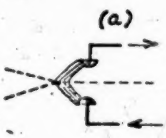


Fig. 25







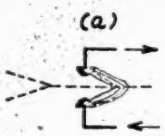
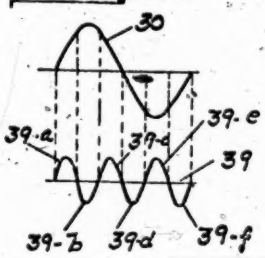
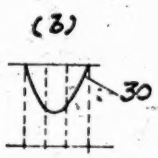
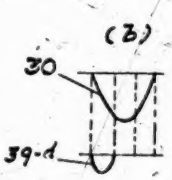
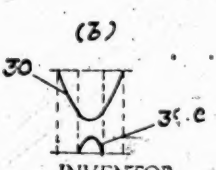


Fig. 26









INVENTOR.

BY Julius E. Foster

ATTORNEY.

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Fig.28

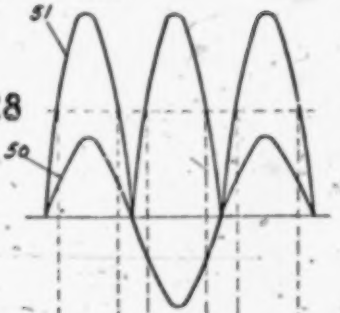


Fig.29

Fig.30

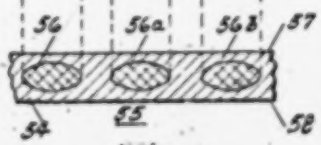


Fig.31

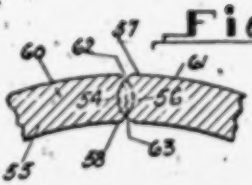


Fig.32

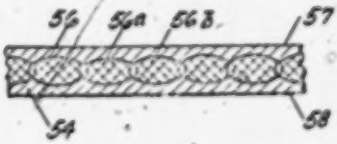


Fig.33

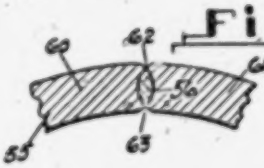
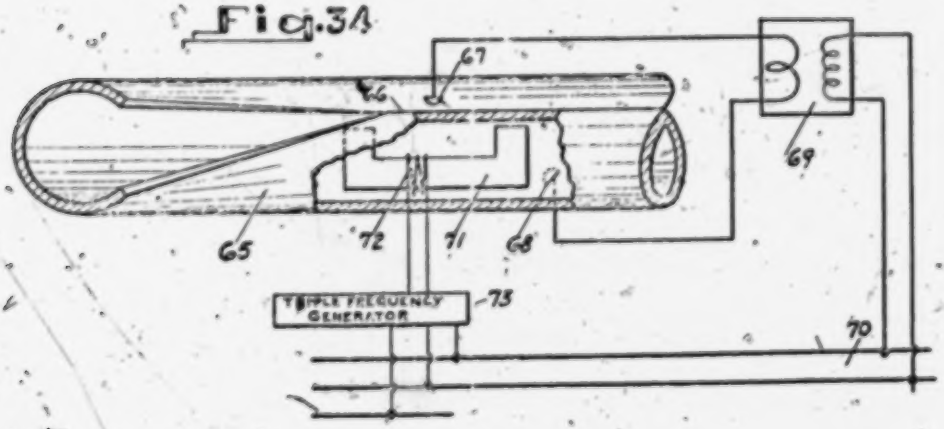


Fig.34



INVENTOR.

BY Julius E. Foster

ATTORNEY.

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Fig. 35

Fig. 36

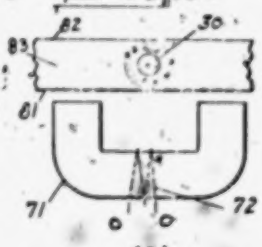


Fig. 37

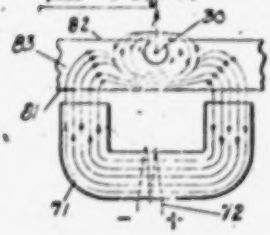
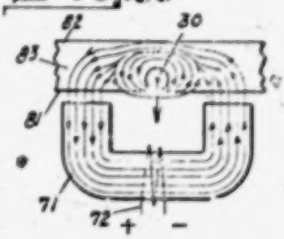
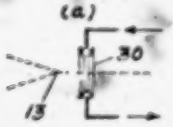
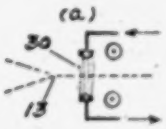
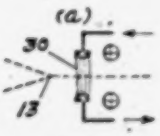


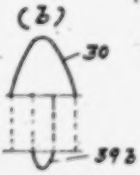
Fig. 38











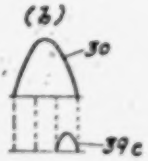


Fig. 39

Fig. 40

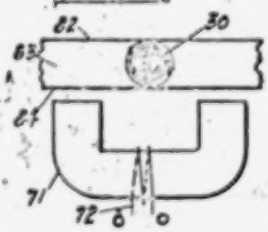


Fig. 41

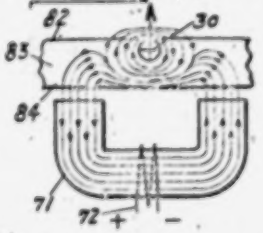
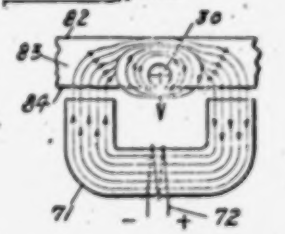
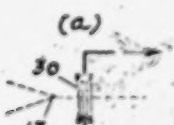
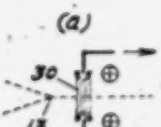
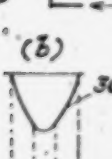


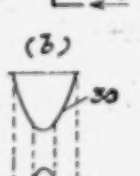
Fig. 42

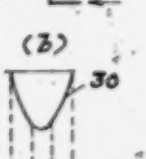












INVENTOR.

BY Julius E. Foster

ATTORNEY.

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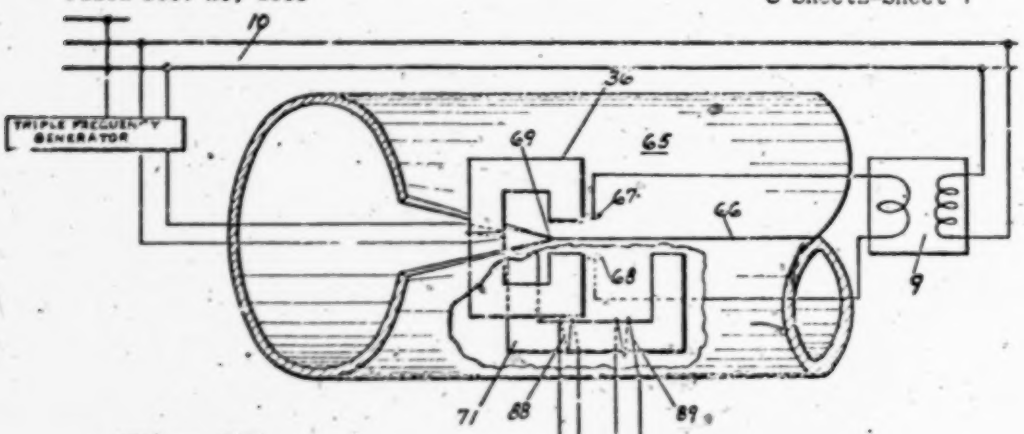
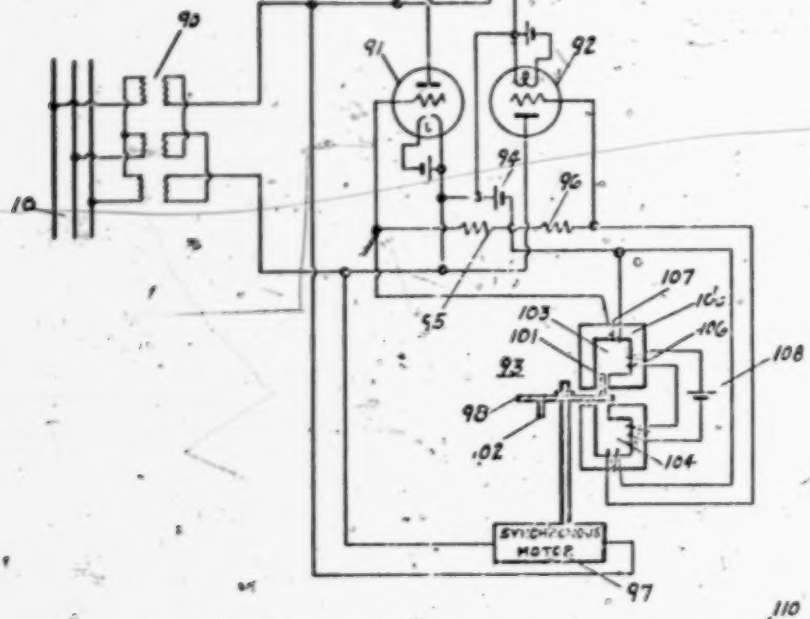


Fig. 43



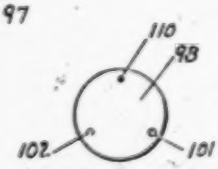


Fig. 43A

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ATTORNEY.

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Fig. 44

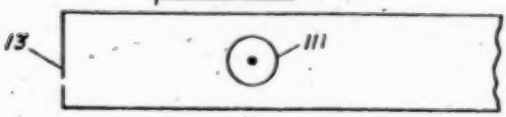


Fig. 45

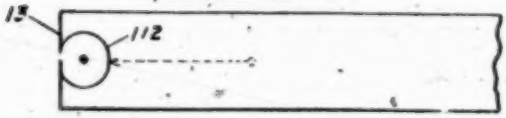


Fig. 46

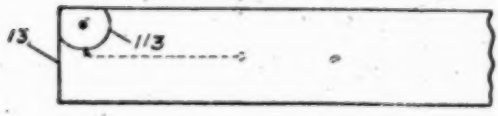


Fig. 47

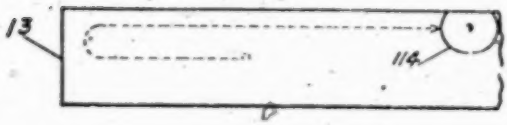


Fig. 48

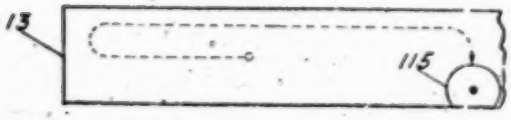


Fig. 49

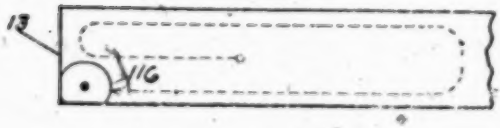


Fig. 50

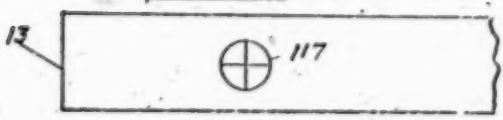
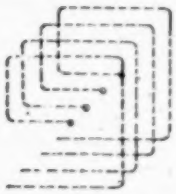


Fig. 51



INVENTOR.

BY Julius E. Foster

ATTORNEY.

Plaintiff's Exhibit PX-1

United States Patent Office 2,882,384 Patented Apr. 14, 1959

2,882,384

WELDING SYSTEM

Julius E. Foster, Jackson Heights, N.Y.

Application December 23, 1953, Serial No. 399,942

23 Claims. (Cl. 219—67)

This invention relates to electric welding, and particularly to a process of welding control that is generally applicable to various welding operations.

Electric resistance welding consists generally in placing two metal elements together in surface-to-surface relation where the weld is to be established between those surfaces, and in then applying the welding current to the two elements in such manner that the current will pass between the contacting surfaces and establish sufficient heat at those surfaces to effect a weld at and between those surfaces.

Theoretically, direct current would seem to provide the most satisfactory medium for welding because of the steady continuous heating condition that it would establish. It is used to some extent, but, because of the difficulty in controlling the energy of large quantities of direct current, such as are necessary for electric resistance welding alternating current energy is preferred, since it may be transformed and therefore more easily controlled. The alternating current energy may be generated at high voltage and transmitted at low current value through relatively small conductors to the place of utilization, and there transformed to low voltage and large secondary current for direct application to the welding operation. The large secondary current can be easily varied, or controlled for starting and terminating the welding operation, by controlling the value of the primary current which is relatively small, or by controlling the primary circuit traversed by the small primary current.

Although alternating current has provided these advantages for practical welding operations, it has suffered from certain limitations, which it would be extremely desirable to remove.

For example, direct current establishes a steady uniform heating effect where the surfaces to be welded are progressively heated and welded. Alternating current, however, establishes spotty heating effects, due to the peak formation of the successive heating waves or impulses. An increase of the direct current, if necessary, would uniformly raise the level of the heating effect. An increase of alternating current, however, would raise the peak values of the heating waves and would establish localized excessive heating, with consequent burning out or melting out of the metal at the spots thus excessively heated.

Because of such spotty welding, with alternating current, the speed of a progressive welding operation must be kept low enough to permit the spot welds to overlap; otherwise the weld, though progressive, is discontinuous.

Increasing the current does not obviate the discontinuity, but merely aggravates the increased spot heating condition referred to above. Thus, with alternating current, the amount of energy that may be introduced into the weld zone according to previous practice, is limited.

Since the usual frequency generally available is 60 cycles, the number of current energy or heating impulses that may be obtained from that frequency is 7200 impulses per minute. While that may seem a large number of impulses, which should be generally adequate, it is nevertheless insufficient to permit the maximum speed of welding that would be otherwise possible, in the art of welding thin wall tubing, for example, if a continuous weld is desired.

While the use of a higher frequency might seem an obvious solution to that problem, in order to increase the number of current, and, therefore, heat impulses, it has been found that the reactance characteristics of the circuits develop sufficient impedance to limit the amount of energy that may be supplied to a welding circuit at higher frequencies than the standard commercial frequency of 60 cycles. The other immediately suggested solution of supplying more welding energy to the circuit at 60 cycles also does not solve the problem, for the simple reason that the application of greater currents merely causes the development of an excess amount of localized heat by each current wave, as previously mentioned, with a resulting burning out of the materials, which ruins rather than establishes a weld.

One of the major fields of application of the process of progressive resistance welding by alternating current has been in the formation of thin walled tubing from strip steel. That process is described in the Johnston Patent 1,388,434, issued August 23, 1921, for the formation of tubing having the general characteristics described in his divisional Patent No. 1,435,306, issued November 14, 1922.

One object of this invention is to provide a method of establishing a continuous progressive weld with alternating current.

Another object of this invention is to provide a method of welding with alternating current that will provide the advantages of equalized uniform heating conditions of direct current.

Another object of this invention is to provide a new process for establishing a progressive continuous weld with alternating current that will permit the welding operation to be performed at a relatively high speed without introducing discontinuities in the weld seam as has been the case heretofore.

Another object of this invention is to provide a welding process wherein and whereby a welding current from an alternating current source may be applied to heat a desired surface at a rate corresponding to a higher frequency than the fundamental frequency of the welding source.

Another object of this invention is to provide a method of welding that shall permit a welding operation to be performed at a higher rate of speed in proportion to the frequency of the applied welding current than has been heretofore possible.

Another object of this invention is to provide a novel process of controlling the welding current in such manner as to permit and to enable more current to be introduced into the weld zone, to develop more heat without burning out the welded metal.

Another object of this invention is to provide a process whereby a welding current stream may be applied to transverse a particular region of a surface to be welded, for a time interval less than the normal duration of the welding current wave, whereby a relatively large current may be applied to perform the welding operation in quick time.

Another object of this invention is to provide a method of welding that shall confine the heating effect of the welding current substantially to the seam surfaces to be welded, and thereby obviate the formation of weakened side zones along the seam.

Another object of this invention is to provide a method

of welding that shall establish a fast welding and cooling action along the seam, and thereby obviate any substantial change in the metallurgical structure of the metal along the seam in response to the welding heat.

By controlling the welding current stream to establish a relatively fast welding and cooling action confined substantially to the surfaces to be welded at the seam, the cohering seam metal may be confined to a relatively thin layer, of fine grain structure, forming a strong bond at the seam.

Another object of this invention, therefore, is to provide a welding process that shall develop a thin weld seam having an extremely fine grain structure throughout the entire welded seam zone to serve as a strong metallurgical bond between the adjoining surfaces welded together.

Endeavors have been made to apply the same Johnston process to butt welding thick walled tubing or pipe, for use as oil country goods. Such pipe would range from ¼ to ⅜ of an inch, or more, in thickness. The butt welding of material of such dimensions presents a problem which was not satisfactorily solved by the Johnston process. For material of that thickness, the weld spot formed an oval spot with its minor axis not extending fully across the width of the edge surface at the seam, from the internal corner edge to the external corner edge of the seam surfaces. Even though the speed of movement of the thick-walled skelp, as a cylinder, through the welding machine, was sufficiently slow to permit the welded spots to overlap lengthwise, so that a substantially continuous weld might be made along the middle of the seam surfaces, there still remained, nevertheless, the unwelded areas between such welded middle sections, or core, of the seam and the inner and outer peripheral edges of butt welded seam surfaces. Such unwelded portions along the edges of the seam areas formed notches or V-like regions, or troughs, with lines along the inner and outer edges of the seam weld, which became stress concentration lines in service, when the finished pipe was subjected to pressure, during operation, or when the pipe became heated by external ambient conditions.

Those stress concentration lines caused defective or weakened zones which would open at the seams. In order to obviate such stress concentration lines the seam weld should be complete over the entire seam surface area.

Another object of my invention, therefore, is to provide a welding process that will insure a complete weld over the entire area of a surface to be welded, so that, for example, in the case of a butt weld, the weld shall be completed from edge to edge of the seam formed by the welding operation, so that no lines or regions of high stress concentration shall be formed along the inner or outer edges of the seam.

Another object of my invention is to provide a welding process that will permit the use of alternating current for butt welding tubes or pipe of relatively thick walls, with a weld that shall be continuous and uniform, and that shall extend transversely across and throughout the entire seam, from the inner edge to the outer edge to obviate the formation of unwelded groove lines, along the edges of the seam, that would act as stress concentration zones during service.

In the Johnston method, the permissible welding current, as a measure of the heat energy that can be introduced into the seam for welding, has to be correlated to the speed of movement of the tubing, through the machinery, and to the pressure upon the butted edges of the material in forming the seam. If that current value should be then exceeded, the heat generated at each weld spot would be sufficient to melt out, or "burn out," a sufficient amount of the metal from the welded seam to form a hole in the seam before the tubing could travel out of the heated weld zone to enable the seam metal to become sufficiently cool to resolidify. That characteristic of progressive resistance welding with alternating current, as heretofore practiced, where each current wave impulse establishes its spot weld, imposes the limitation upon the amount of current that may be supplied to the welding zone, and, therefore, the limitation in the amount of heating energy that may be supplied to the weld zone.

It is to overcome the limitations of such prior process, and to procure the resulting advantages, that this invention is directed.

This invention presents a new and fundamental principle of control in welding, which has general application in the field of resistance welding, whether for spot welding or for continuous progressive welding over a length of surface.

Generally, the major object of this invention is to provide a welding system in which the welding current is controlled and moved by an external electro-magnetic field in such manner as to cause the welding current to scan and to heat-weld the entire areas of the surfaces that are to be welded to each other.

In its most general aspect, this invention involves the application of an external electro-magnetic control flux field, which may be made up of one field or of more flux fields, to control the normal welding current stream to cause it to move along selected regions of the welding zone, in the nature of a scanning operation, with a relatively fast action, to establish a welding condition throughout and over the entire selected area that is to be welded. By reason of the quick incisive sweeping action of the welding current stream when so controlled, and its extremely rapid heating influence upon the surfaces to be welded, the actual value of the current, considered as a heat effect, may be largely increased over that value to which the current would have had to be limited in the prior Johnston process.

Thus, by reason of the fast action and the scanning or sweeping action of the current, the advantage achieved is to be able to introduce a much larger amount of heating energy into the weld zone without the danger of localized heat and burn-outs; the welding operation itself is effected much more rapidly so that the weld is made and completed before any metallurgical disturbance can take place that would permit any of the constituents of the metal to come out of solution and weaken the metal; and the welding result is established throughout the entire areas in the surfaces at which the weld is desired, so that no unwelded areas are left along the seam edge surfaces, where stress concentration zones would result; and the heating effect is confined substantially to the surfaces at the seam so that the weld metal, the metal in and forming the seam, constitutes a thin layer of strong fine grain metallic cement bonding both welded surfaces as a strong coherent structure.

In order to overcome the discontinuity in the seam, due to unwelded portions between the spot welds of thin wall tubing, as made by prior practice, this invention contemplates the disposition of means to establish an electro-magnetic flux field in the region of the welding current stream, adjacent the seam cleft, and thereby effect a magneto-motive action between such external flux field and the welding current stream to sweep or reciprocate the current stream back and forth through a space of pre-determined length in the seam, thereby to cause the welding current stream to establish a welding action longitudinally along the seam, instead of making the spaced spot welds as in the prior practice.

Such external controlled flux fields should preferably include an alternating flux field having a frequency greater than the frequency of the welding current where an alternating welding current is used. For example, if the welding current is a 60 cycle current, the control flux should preferably, for convenience, be a multiple of that frequency. By thus reciprocating the welding current along

the seam, a much greater area of surface may be welded during each current wave or impulse, and a much greater amount of heating energy can be safely applied to the seam to establish the welding operation, due to the shorter length of time the welding current is permitted to traverse the surface being welded.

In the case of thick wall pipe, the same reciprocation of the welding current stream is established according to the principles of this invention. In addition, however, it is necessary to establish a weld in the outer and inner longitudinal edges of the seam, as well as between the weld spots along the seam surfaces. The external flux field should, therefore, be such as to establish both a reciprocating movement of the welding current stream longitudinally along the seam, and also to establish a force that will move the current stream outwardly in the seam towards the outer edge of the seam, and inwardly in the seam towards the inner edge of the seam during alternate reciprocations. For this application, this invention therefore contemplates the use of a flux field having two component effects, to force the welding current stream radially inward or radially outward, while at the same time reciprocating the welding current stream along the seam.

In the case of the thin wall butt-welded tubing, the external magnetic flux may be established to extend perpendicularly through the tubing in the region of the seam and to include the seam along a distance within which the welding current is to be controlled.

In the case of the thick wall butt-welded pipe, a flux field similar to that to be used with the thin wall tubing should be applied and an additional flux field that will mainly lie lengthwise within the seam in such manner as to make the pipe serve as an armature for the flux producing magnet. The two fluxes will then serve to establish the reciprocating action of the welding current and the radial shift of the welding current at the same time.

The manner in which this invention is applied to thin wall tubing and to thick wall pipe is illustrated in the accompanying drawings, in which:

Figure 1 is a schematic view illustrating the layout of a welding system for tubes made from strip metal.

Figure 2 is a partial schematic plan view of a tube welding system, illustrating the disposition of the current supplying electrodes adjacent the seam cleft, and the side-pressure rolls behind the electrode rolls.

Figure 3 is a graph of one cycle of an alternating weld current sine wave.

Figure 4 is a plan view of the seam, and Figure 5 is a vertical sectional view along the seam, with both views related to the current wave cycle of Figure 3, when the welding is done at a high rate of speed, sufficiently fast to separate the successive weld spots in the seam.

Figure 6 is a graph of a sine wave representing the weld current.

Figure 7 is a view of a seam surface similar to that in Figure 5, with the welding done at a speed sufficiently low to permit the welded spots to overlap, to establish a continuous weld along the seam.

Figures 8 and 9 illustrate the relationship between high pressure at the seam surfaces and the resultant heating effect in the seam, between the surfaces.

Figures 10 and 11 illustrate the relationship between low pressure at the seam surfaces and the resultant heating effect between the surfaces.

Figure 12 is a schematic illustration of a group of spaced welded spots along a seam, and Figure 13 is a graph illustrating the resistance distribution, along the seam, with relation to the spaced welded spots of Figure 12.

Figure 14 is a schematic view of a welding current stream between the electrodes at the beginning of a current wave impulse.

Figure 15 is a similar view showing the distribution of the current stream with respect to a heated seam zone after the beginning of the impulse.

Figure 16 is a similar view illustrating the disposition of the current stream when shifted to its extreme left at the cleft, or initial point of contact between the seam edges.

Figure 17 is a schematic diagram of a welding system modified according to one phase of this invention, to establish reciprocating length-wise shifting of the welding current stream along the seam.

Figure 17–A is a simple diagram of a transformer arrangement whereby a triple-frequency single-phase current may be derived from a three-phase circuit, for use in the system of Figure 17; and Figure 17–B is a graph illustrating the relationship between the single-phase fundamental or base frequency welding current and the triple-frequency control current of Figure 17.

Figures 18 to 21, inclusive, are schematic views illustrating the relationship between the welding current stream through a seam surface, and the control magnetic flux set up by the control current, with the progressive actions effected by the change of polarity of the control current during the positive wave of the welding current of the system of Figure 17.

Figures 22 to 25, inclusive, are similar views showing the progressive relationship between the welding current stream and the control flux set up by the control current, during the negative wave of the welding current.

Figure 26 is a simple graph of one cycle of the welding current, and the three related in-phase cycles of the triple-frequency control current, in the system of Figure 17.

Figure 27 is a simple schematic view illustrating the provision of a shaded pole on the control magnet to provide a travelling flux field.

Figure 28 is a simple graph showing the relationship between the alternating current and the heating impulses.

Figure 29 is a graph related to Figure 28 to illustrate the relative disposition of heated regions along a welded seam.

Figure 30 is a schematic sectional view taken longitudinally along a welded seam and showing the disposition of welded spots in a thick-wall pipe, made at a speed sufficiently high to space the welded spots from each other.

Figure 31 is a transverse sectional view across the seam illustrating how a central disposition of the weld zone fails to extend to both the inside and the outside peripheral edges.

Figure 32 is a view similar to Figure 30, but showing the disposition of the weld spots in overlapping relation when the welding action is performed at slow speed.

Figure 33 is a transverse sectional view across the weld seam on a pipe welded as in Figure 32, illustrating a failure, similar to Figure 31, to reach to both the inside and the outside peripheral edges.

Figure 34 is a schematic diagram of a welding system modified according to this invention, to establish radial reciprocation of the welding current stream.

Figures 35 to 38, inclusive, are schematic views illustrating the progressive effects of the control flux set up by the control current upon the welding current stream during the positive wave of the welding current, in the system of Figure 34.

Figures 39 to 42, inclusive, are similar progressive views illustrating the effect of the control current magnetic flux upon the welding current stream during the negative wave of the welding current, in the system of Figure 34.

Figure 43 is a simple diagram of a welding system, embodying this invention, with a magnet for longitudinally reciprocating the weld current stream, and a magnet for radially controlling the weld current stream, with means for selectively energizing the radial control magnet with selected control impulses.

Figures 44 to 50, inclusive, are progressive views show-

ing the step-by-step movements of the weld current stream in scanning a seam surface according to the control imposed in the system shown in Figure 43.

Figure 51 is a schematic perspective view of the progressive overlapping paths of the welding current stream of Figures 44 to 49, inclusive, shown in exploded or opened position, as a group of progressive helices.

As illustrated in Figure 1, a system for forming tubes from strip material, by shaping the strip into cylindrical form and then welding the strip edges along the seam thus formed, comprises generally suitable mechanism for supplying strip material 1 from a reel 2 to a forming machine 3, to form the strip into a cylinder 4 with the outer edges contacting along a seam 5, which is guided by a suitable guiding finger 6 to guide the cylinder 4 between two electrodes 7 and 8, to permit a welding current derived from a welding transformer 9 to be supplied to the cylindrical tube 4 across the seam 5 to generate sufficient heat in the seam to effect a welding between the engaging seam edges. The seam edges are held in close contact by two pressure rollers 11 and 12 to hold the welded edges together until the heated metal of the seam can cool and solidify to hold the tube closed, after passing out of the weld zone between the electrodes.

As shown in Figure 2, the strip 1, when formed into a cylinder, makes the first contact between the side edge surfaces at a point that constitutes a cleft 13, intermediate the guide finger 6 and the plane through the electrodes. The guide finger is preferably of the nature of a file to clean the edge surfaces of the strip by removing any rust or dirt adhering to those surfaces.

In Figures 3, 4, and 5, is illustrated, generally, a relationship between the two waves 14 and 15 of a weld current cycle and the weld spots produced thereby. The current waves 14 and 15 are of opposite polarity, but their heat effects represented by wave impulses 14–*a* and 15–*a* have no polarity characteristics.

The effective value of a sine wave is approximately seven-tenths of the maximum peak value. The heat effect is therefore represented by a value below the peak value, and, for satisfactory welding operation, the heating effect or heating value of an alternating current should be sufficient to melt the metal in a thin layer on the edge surfaces to form a weld seam between those surfaces.

As schematically shown in Figure 3, the heat impulses 14–*a* and 15–*a* have effective heating values measured by the height of dot and dash line 16 above the zero or base line. Broken line 16–*a* schematically represents the amount of heat necessary to establish a melting of the seam edge surfaces for the welding action.

If the heating effect of the heat impulses 14–*a* and 15–*a* reaches the value represented by line 16–*a*, a spot of metal will be effected at the seam, on both surfaces, and will form a weld spot 17 in the seam, as in Figure 5, which will look like the tapered spot shown in Figure 4. Relatively the formation and the location of the weld spots 17 will be governed by the time and place occurrence when the heat impulses establish the effective heat values that are at least equal to the melt values represented by line 16–*a*.

If the metal tube is kept stationary, the heat impulses will pile up on one spot at the seam. If the tube is moved past the electrodes, while current flows between the electrodes, the locations of the spots will be controlled according to the times when the heat impulses reach their effective values. If the speed of movement of the tube is high, the weld spots 17 may be separated, as shown in Figures 4 and 5. The spaces 19 along the seam, between the weld spots 17, will be unwelded, and will open sufficiently, under excess internal pressure, to permit leakage through the seams at those points.

If the speed is slower, the current waves of the welding current, shown in Figure 6, will establish closely disposed weld spots 17, as in Figure 7, that will overlap sufficiently to establish a continuous weld along the seam.

In resistance welding, the pressure between the edge surfaces at the seam is an important factor in controlling the heat development in the seam.

The amount of heat that is generated in the weld, directly at the contacting edge surfaces, can be controlled by varying the pressure between the contacting seam edges. The reason therefor becomes clear upon consideration of Ohm's law. The energy at the weld is the product of the weld current I and the voltage drop E, or *IE*. The voltage drop E, in turn, is the product of the current I and the resistance R, between the edges at the seam, or *IR*. The energy is therefore represented by the well-known expression I^2R. The heat developed in the seam is therefore proportional to the resistance of the contact between the seam edges.

If the contact pressure between the edges at the seam is high, the resistance will be low, and the amount of heat generated in the seam will be small. Conversely, if the contact pressure is low between the edges at the seam, the resistance will be high and the amount of heat developed in the seam will be large. Thus, the heat in the weld can be inversely controlled by the pressure at the weld, for the same current value.

Therefore, where the pressure is high and the resistance low, as in Figure 8, the heat developed is low, as shown in Figure 9. And where the pressure is low, as in Figure 10, the resistance is high and the heat is high, as in Figure 11.

Thus, for the same value of weld current, the heating effect may be high or low, depending upon the contact pressure at the seam edges. If that pressure is kept constant, however, the heat effect will vary as the square of the current.

Where such pressure was maintained constant, as in the manner heretofore practiced, the amount of current that could be applied to the seam was limited to a quantity that would not generate sufficient heat at each weld spot to cause the metal to drop out.

The quantity of current that could be safely applied to the seam was also governed by the speed of movement of the tube through the weld zone and past the welding electrodes. A fast moving tube could safely receive more current in the seam than a slow moving tube, since the heating effect would be more distributed in the fast moving tube, and the tube would be cooled faster.

A particular advantage of high speed welding is that the change in the metallurgical structure of the metal at the seam edges is reduced to a minimum. Thus, in the welding of steel, even with a high carbon content, a high speed in the welding action permits only a small change in the carbon distribution, and does not appreciably withdraw the carbon from its solid solution in the metal, along the seam, as is permitted by slow welding, where sufficient time is available for extensive metallurgical redisposition in response to the generated heat impulse of the weld current.

That desirable feature of maintaining the original metallurgical structure is substantially achievable with high speed welding, and is one of the advantages achieved by this present system.

With welding current of standard commercial frequency of sixty cycles, the heating time, measured by the time of contact between the electrodes and the metal being welded, is relatively short. If that time could be diminished still further, while effecting a complete weld, however, there would be still less time for change of metallurgical structure in response to the welding heat impulses, and any such tendency would be arrested that much more quickly.

If the frequency of the welding current were increased, higher welding speed would appear theoretically possible. The reactance, or electrical impedance, of the system would be so increased, however, that the current value could not be sufficiently increased to provide a current

impulse with sufficient heat generating content to effect a weld.

Similarly, with current of standard commercial frequency of sixty cycles, the successive weld spots 17 as formed in a progressive welding operation, are spaced from each other, as indicated in Figure 5. The metal zones 19 between those weld spots 17 along the two edges at the seam, are not welded together.

Here, again, it would appear that the use of a current of higher frequency would serve to locate the weld spots closer together, and, therefore, cause them to be overlapping and continuous, to establish a continuous progressive weld along the seam.

But the higher frequency current is unsatisfactory for that purpose due to the increased impedance of the system to higher frequencies, as already explained.

During a welding operation at high speed, with the weld spots spaced from each other, as shown in Figure 12, the resistance along the weld is distributed as shown in Figure 13. Where the seam is welded at the spots 17, the resistance across the seam is small, as indicated by the bases 17–*a* of the graph of Figure 13. At the spaces 19 between the weld spots 17, the resistance across the seam is high, as indicated by the peaks 19–*a* in Figure 13.

As each current impulse, whether positive or negative, crosses the seam 5, the metal at the seam edges becomes heated. The manner in which the heated metal along the seam controls the weld current is shown in Figures 14, 15, and 16.

As shown in Figure 14, a current impulse of weld current, represented by current streams, traverses the metal across the seam 5 as it passes between the two electrodes 7 and 8. The metal traversed by the current becomes heated and welded. While heated, its resistance is increased. So long as the heated metal, indicated by the dark section 31 (exaggerated for clearness) lies in the path between the electrodes 7 and 8, the current impulse, whether it is the one that heated that metal, or whether it is the impulse following the heating impulse, will shift to the left, to the cold metal of the seam, adjacent and behind the heated metal, as shown in Figure 15.

As soon as the current stream 30 between the two electrodes is diverted from a direct straight-line path between the two electrodes 7 and 8, the electro-magnetic flux of the current stream itself acts upon the stream as a movable conductor and moves the V-point 32 of the current stream to the extreme possible left-hand position along the seam, to the place where the seam edges are initially engaged at the cleft 13, as indicated in Figure 16.

As the metal is progressively moved along between the electrodes, each current impulse is similarly moved to the cleft at the engaging seam edges, where the resistance between engaging edges of the seam is highest. The heating effect is therefore maximum at the cleft according to Ohm's law, as previously explained. It is this action which is utilized to advantage in this system of progressive resistance welding. The increased heating action at the cleft, due to the high resistance at that point, heats the contacting metal of the two edges at the seam to a temperature that melts the layers of metal on both contacting edges so the molten metal may coalesce to form the weld between the two engaging edges. As the metal of the seam proceeds on its way, the heat of the seam edges is transmitted back into the body of the adjacent metal and dissipated, and the seam is rapidly cooled, and the coalesced weld spot solidified. The pressure rolls 11 and 12, shown in Figure 1, serve to hold the seam edges together long enough to permit the weld spot to solidify. To the extent that the heated tube may be expanded to a diameter somewhat slightly larger than the initial diameter, the pressure rolls maintain an increased reaction pressure on the seam of the tube being welded. The pressure rolls are adjustable, however, so the pressure may be varied under different welding conditions to establish optimum operation.

For many applications, where a tube is used for structural purposes, it is satisfactory to provide a tube whose seam is held closed, even though the weld spots are spaced as in Figures 5 and 12, and even though the seam is not continuously welded along its length.

For other applications, where the tube will be subjected to internal pressures, as in grease guns, for example, or where the tube is to serve as a conduit, the seam should be completely welded along its length. With welding methods heretofore available, such a continuous weld could be effected only by a slow welding operation, so that successive heat impulses would overlap. Such slower welding operation would produce less tubing per unit of time, and would not utilize the maximum capacity of the welding machine. Moreover, the slower welding operation retains the heated metal of the seam in the weld zone long enough to permit the original metallurgical structure of the metal at and along the seam to be modified by the heat of welding, and to segregate the elements of the metal from their normal proper disposition. The welding heat would not be dissipated quickly, at such slow speed, but would be transmitted to the metal in the side zones adjoining the seam and would heat that metal to a sufficient degree of softening to cause weakening of the metal along such side zones.

Thus, for a continuous seam weld, the welding operation of the prior art must be slow enough to permit weld spot overlapping, with the attendant disadvantages of overheating along the seam and of undesired metallurgical modification.

Higher speed of welding operation of the prior art results in a discontinuous weld. The use of high frequency current for more frequent and, hence, closer weld spots is not possible. The use of greater current quantities is impossible, according to prior art practices, because each current impulse would generate more localized concentrated heat than necessary merely for the welding operation, and would melt out enough metal from the seam to leave a hole through the wall of the welded tube, at the seam.

The method of the present invention, as herein disclosed, overcomes the various difficulties of the prior art, outlined above, and permits a continuous weld to be made at high speed with welding current of standard commercial frequency. An incidental advantage is the rapid cooling of the welded surfaces, with a retention of the original metallurgical structure and a confining of the weld action to the edge surfaces only of the metal at the seam. In order to establish the continuous weld, more heat is necessary. By this method, such increased quantity of current is supplied to the weld zone without overheating and without burning out the metal at the seam.

One form of system operating in accordance with this invention is shown in Figure 17. In addition to the several elements employed in Figure 1, a system for electro-magnetically controlling the welding current stream is employed to cause the welding current stream to traverse and scan the contacting edge surfaces at the seam.

By controlling the welding current stream to cause it to scan the surfaces to be welded, the welding action is not limited, as in the prior art, solely to the spot heated by the peak of the current impulse, but, instead, the welding action is controlled and caused to take place over the entire surfaces of the contacting edges at the seam.

Moreover, by moving the welding current to scan the seam edge surfaces, the heating action of the weld current can be safely controlled both as to speed and current quantity. The fast traverse of the weld current stream on the seam edge surfaces shortens the time of heating and permits the use of a larger current quantity for

welding, since the short heating time does not permit sufficient heat to accumulate to melt out the metal at the seam. The action is thus like the sweep of a hot welding brush between the two engaging edge surfaces, to melt the metal progressively along those edges so the molten metal may progressively coalesce and weld the seam edges together.

The method of operation, and the apparatus employed, may now be considered.

As shown in Figure 17, current from an alternating current supply circuit 10 is transformed by transformer 9 and supplied to the welding electrodes 7 and 8 to cross and heat the seam 5 of the tube 4 being formed. Normally, the current stream of each current impulse travels the space between the electrodes as shown and explained in Figures 14, 15, and 16, to form a weld spot at the time of the peak of the current impulse as indicated by the related Figures 3, 4, and 5.

In order to cause the current impulses to also heat the spaces 19 between the weld spots 17, means is provided, illustrated, by way of example, simply as an electromagnet 35, to establish an electromagnetic control flux field to act upon the weld current stream as a movable conductor, and to move the weld current stream as a movable conductor through a predetermined path.

The magnet 35 and the welding current stream act as an electric motor, the magnet being stationary and the current stream being movable. The direction of movement of the weld current stream depends upon the relation between the flux polarity and the current polarity; and the speed of reversal of movement depends upon the frequency of alternation of the control flux.

The magnet 35 is illustrated as embodying a single magnet structure 36 and energizing means shown as a single coil 37. Energy for the coil 37 may be derived from any suitable source having a frequency that is preferably a multiple of the weld current frequency. By way of illustration, a triple-frequency generator 38 is shown, consisting of a three-phase star-delta transformer with the secondary delta open at one vertex, as in Figure 17–A, to provide a single-phase circuit connection for the magnet winding 37. With such a connection, the third harmonic of the fundamental frequency is derived at the open vertex of the secondary delta to provide the triple-frequency control current 39. The control-frequency generator should preferably be energized from the same source which supplies the welding energy, so the control frequency can be synchronized with the fundamental weld current frequency, as in Figure 17–B.

Another suitable frequency generator, or frequency changer, may be employed, that will provide the frequency desired to control the weld current. It is merely necessary to synchronize the control frequency with the weld current frequency, as in Figure 17–B, for optimum operating conditions.

The manner in which the higher frequency control flux controls the position of the weld current stream, to shift the weld current stream back and forth along the seam to scan and heat the engaging seam edges, is illustrated in Figures 18 to 26, inclusive.

Figure 18 illustrates the direction of the weld current in a downward direction between the electrodes, corresponding to the positive current wave in the weld current circuit.

Figure 19 represents a schematic vertical elevation of the seam along and in the direction of the lines 19—19 of Figure 18, with the control magnet 35 in position adjacent the electrode plane, and with the weld current stream 30 represented by the heavy solid line circle and the central arrow point, or dot, indicating a positive wave (Fig. 19–*b*) with current movement toward the observer. The control magnet 36 is unenergized, and the current stream 30 is in the plane of the electrodes.

When the electromagnet coil is energized, as in Figure 20, by a positive wave of control frequency current 39–*a* (Figure 20–*b* and Figure 26), the weld current stream 30 is forced to the left, Figure 20–*a*, to the cleft 13 of the seam 5, for substantially the duration of the control frequency positive wave 39–*a* of Figure 20–*b*.

During the next half cycle 39–*b* of the control frequency, when the magnet coil is energized by a negative control wave 39–*b*, as in Figure 21–*b*, while the weld current 30 is still positive, as in Figure 21 and Figure 21–*b*, the weld current stream 30 is shifted to the right, away from the seam cleft, for substantially the duration of the control frequency negative wave 39–*b* of Figure 21–*b*.

During the next half-cycle 39–*c* of the control frequency, the control current 39 is again positive, while the weld current 30 is still positive, as previously shown in Figure 20. The magnet control coil 37 is therefore energized by a positive impulse 39–*c* again, as in Figure 20 and Figure 26, and the weld current 30 is shifted back again to the left to the seam cleft 13.

Thus, during the positive half wave of the welding current, the polarity of the control circuit changes three times and shifts the welding current stream 30 back and forth to scan a substantial length of the seam edges. If the seam is being moved past the welding electrodes, during such conditions, the heating effect of the welding current stream will be distributed over the moving seam length, instead of being concentrated to form a weld spot in the moving seam, as in the prior art.

Moreover, the shifted welding current 30 traverses each small increment of area of the seam edges for a shorter interval of time than where the welding current is not shifted, as has been the case in the prior art. Consequently, a greater quantity of welding current may be employed to effect fast heating, since the heating action of the welding current is quickly terminated at any area, before sufficient heat can be localized and accumulated to burn out the metal of that area from the seam.

When the polarity of the welding current 30 reverses, the scanning action of the welding current continues in the same manner as already described, and is illustrated in Figures 22 to 25, inclusive.

In Figure 22, the welding current is in the reverse direction, that is, it is upward between the electrodes and across the seam. That current is indicated in Figure 23 by the solid line circle 30 containing the cross, and represents current flowing away from the observer. The magnet coil is not energized, so the weld current is shown centrally located in the plane of the electrodes, in Figure 23.

In Figure 24, the welding current continues negative, and the control magnet is now energized by a negative current impulse 39–*d* of Figure 24–*b*. Under such conditions, with both currents instantaneously of the same polarity, the welding current is shifted to the left to the seam cleft, Figures 24–*a* and 24–*b*.

In Figure 26, is shown the relationship between one cycle of the fundamental frequency of the welding current 30 and three cycles of the control current 39. It will be observed that the first wave of the control current is of the same polarity as the corresponding wave of the fundamental frequency.

In this specification describing the system, the welding current and the control currents are considered as being in phase, that is, that the zero points of both waves occur at the same time.

When the control current polarity again reverses to positive, as wave 39–*e* in Figure 26, the conditions become as shown in Figure 25, and the welding current is shifted to the right, since it still is of negative polarity, opposite to the polarity of the control current.

The weld current 30 continues negative, as shown in Figure 26, for the duration of another half-wave 39–*f* of control current, during which time the welding current

30 is again shifted back to the left to the seam cleft, in the manner already described as shown in Figure 24.

Thus, with triple-frequency control current, the welding current is shifted once in one direction and twice in the opposite direction. With double frequency control current, the weld current stream would be shifted only once in each direction to scan the butting seam edges; and with a control frequency four times the fundamental welding frequency, the welding current stream would be shifted twice in each direction. The appropriate control frequency may be employed, according to conditions encountered or desired.

Where the metal being welded is relatively thin, so the width of the edge presented at the seam will be relatively narrow, the weld current stream section will be of sufficient diameter to extend across the full width of the seam surface area and thereby effect a complete weld along the entire area of the surface at the seam from the inner to the outer peripheral corner edge of the seam surfaces.

Here illustrated is an application where the welded surfaces are butt welded. The same operation may be applied to lap welds where the area of the lapped surfaces is such that the weld current stream would be wide enough to cover the width of the area to be welded.

The point that must be observed is that the control magnetic flux must be perpendicular to the welding current stream, so that a dynamo-electric reaction may be established between the control flux and the welding current stream.

By the fast reciprocation of the weld current stream over the seam surfaces, those surfaces are heated quickly and cooled quickly. The original metallurgical structure is thus substantially retained.

For optimum operation and results, the value of welding current supplied to the seam should be co-ordinated with the speed of movement of the tubing through the machine, the size of the material surface to be heated, the frequency of the control circuit, and the pressure between the surfaces to be welded.

The continuous weld thus formed will produce a thin seam layer of fine grain structure serving as a strong coherent metallic bonding material over the entire seam surfaces and strongly holding them together.

A modified form of the control magnet is shown in Figure 27, where the magnet 45 is provided to be merely illustrative of electromagnetic means for setting up a travelling magnet control flux field. The magnet 45 is shown provided with a shaded pole structure 46 to establish a secondary or auxiliary flux that co-operates with the main flux to establish the traveling flux condition.

Thick-wall or wide-zone welding

Where the material to be welded into a pipe is relatively thick, as, for example, more than one eighth of an inch thick, the current stream may not be sufficiently wide or sufficiently distributed, over the width of the surface to be welded, to assure a complete weld from the inner to the outer edge of each surface at the seam.

In a thick-wall pipe, the prior art method of welding has produced results and conditions schematically illustrated in Figures 28 to 33, inclusive.

Figure 28 shows the welding current represented by the solid-line sine wave 50, and the corresponding heating impulse effects represented by the waves 51, all above the zero base line.

Figure 29 illustrates schematically the relation of several weld spot zones 52 to the heat impulse waves 51 and the current sine waves, under conditions which would separate and space the weld spots.

Figure 30 illustrates schematically an elevational view along a seam edge surface 54 of a thick-wall pipe 55, showing the disposition of a series of weld spots 56, 56–*a* and 56–*b*, as developed by a series of heat impulse waves 51, as in Figure 28. The weld spots 56, 56–*a* and 56–*b* are located intermediate the upper and the lower edges 57 and 58 of the seam surface 54, and are shown separated and spaced as they would be if the pipe were moved at a high speed past the welding electrodes used for that pipe. At a slower speed, the weld spots would be closer together or would even overlap lengthwise, depending upon the speed.

A transverse view of the seam region, taken through a weld spot 56 along the seam, is shown in Figure 31, where two portions 60 and 61 of the pipe are joined at the seam by a weld spot 56 that does not extend vertically through the entire height of the seam. Consequently, two V-shaped notches 62 and 63 are formed lengthwise along the top and bottom edges of the weld spots in the seam, at the inner and the outer edges of the seam.

The top and bottom edges of the weld spots, that constitute the apices of the notches, thus become stress concentration lines that tend to rupture the welds and to open up the seam. This situation obtains whether the weld spots are separated from each other due to high speed welding, as shown in Figure 30, or whether the weld spots overlap, due to slower welding, as shown in Figure 32. In the latter case the seam edge surfaces are still not completely welded, but have the V-shaped notches along the inner and the outer edges of the seam, as shown in Figure 33, which indicates a structure similar to that of Fig. 31.

Such V-shaped formations along the edges of a seam therefore constitute dangerous and destructive formations that tend to weaken and rupture a seam with an effective force that is entirely out of proportion to the relationship between the unwelded areas of the seam and the welded spot areas.

To eliminate this weakening influence, the seam surfaces must be welded over their entire areas from top to bottom edges of the seam. To accomplish and to assure such a complete weld, the welding current must be controlled to scan the entire edge surfaces at the seam, so the weld will be established over the entire surfaces. Such a scanning operation must involve, in part, a radial movement of the current stream, from a position across the upper edge of the seam to a position across the lower edge of the seam, in order to heat every part of the edge surfaces at the seam.

The radial part of the movement of the welding current stream is controlled by a system whose principles are shown in simple schematic form in the diagram of Figure 34. As shown, pipe 65 is to be welded along its seam 66 by a current stream between the two electrodes 67 and 68, connected to the secondary winding of a transformer 69 energized from an alternating current circuit 70 of standard commercial frequency, such as sixty cycles. An electromagnet 71 is disposed longitudinally along and adjacent the seam 66 to establish a control magnetic flux field in, and parallel to, the seam 66, to be perpendicular to the normal weld current path between the electrodes. By energizing the electromagnet 71 in one direction or the other, the weld current can be controlled to shift its position radially, from the inner peripheral edge of the seam to the outer peripheral edge of the seam.

The action of the electromagnet 71, in Figure 34, is similar to the action of the electromagnet 35 in Figure 17, insofar as the magnet flux reacts upon and moves the weld current stream. The disposition of the control flux is shifted ninety degrees, however, so the resultant movement of the current stream will be up and down in the seam, whereas in the system of Figure 17 the weld current stream was moved back and forth longitudinally.

The magnet 71 is energized by a coil 72 which is connected to be energized from a multiple frequency generator 73, which, for example, may be a triple-frequency source similar to the source 38 in Figure 17.

The manner in which the magnet 71 controls the

position of the weld current stream is illustrated in Figures 35 to 42, inclusive.

Figure 35 illustrates the direction of the weld current in a downward direction between the electrodes, corresponding to the positive current wave in the weld current circuit.

Figure 36 represents a schematic longitudinal and vertical elevation of the seam along and in the direction of the lines 36—36 of Figure 35, with the control magnet 71 adjacent and spanning the electrode plane, and with the weld current represented by the heavy solid line circle 30 and its central dot representing an arrow point, indicating a positive current wave flowing toward the observer. The control magnet 71 is unenergized, and the current stream 30 is in the plane of the electrodes.

For the system of control described by way of example in this case, the first control wave of each three-wave group associated with each fundamental welding current wave, of each polarity, is not supplied to the control magnet. Only the second and the third control frequency waves are supplied to the magnet.

When the electromagnet 71 is energized, as in Figure 37, by a negative wave of control frequency current, while the weld current is positive, the weld current stream 30 is moved upward in the body of the pipe to the upper edge or corner 82 of the seam surface 83 that is to be welded to form the seam. Figure 37 illustrates how the magnet flux reacts upon the flux surrounding the weld current stream 30 to establish a motor force tending to move the current stream 30, as a movable conductor, away from the flux field set up by the magnet 71.

When the magnet flux field is reversed, by a positive control current impulse as in Figure 38–*b*, while the weld current is still positive as in Figure 38, the reaction between the magnet flux and the weld current flux is reversed from that in Figure 37 and the weld current stream 30 is forced downward to the lower edge 84 of the surface 83.

When the polarity of the welding current reverses, as in Figure 39, the direction of the flux field around the weld current stream reverses, as in Figure 40, where the circle 30 represents a negative weld current flowing away from the observer.

The reactions between the weld current flux and the flux field established by the electromagnet 71, as shown in Figures 41 and 42 are similar to the reactions shown in Figures 37 and 38, the reactions being such as to move the weld current stream in one direction or the other, to the corresponding edge of the surface to be welded to form the seam.

Thus, with electromagnetic means, generally represented by the electromagnet 71 of Figure 34, the weld current stream may be shifted radially from edge to edge through the surfaces to be welded to form the seam. Similarly, by electromagnetic means, generally represented by the electromagnet of Figure 17, the weld current stream may be shifted or reciprocated, longitudinally along the surfaces to be welded to form the seam.

In a thin-wall tube the longitudinal reciprocation may be sufficient for a satisfactory weld if the weld stream forms a weld spot or area wide enough to extend between both corner edges of the seam surfaces to be welded as a butt weld. Similarly, a lap weld of thin material may be formed, where the width of the area of overlap is within the width of the weld spot or area that would be formed by the weld current stream as it is reciprocated.

In the case of a lap weld, the magnet position would have to be changed, of course, so the magnet flux would be perpendicular to the weld current stream, to establish the proper magneto-motive action.

In the case of a butt-weld between thick-wall edge surfaces of a pipe, where the width of the weld spot formed by the weld current stream is not co-extensive with the thickness of the wall or the width of the butt edge surface to be welded, the current stream should be moved to scan the entire surface area to establish a welding action over the entire area of the butt edge surface to be welded. To accomplish such scanning action, suitable electromagnetic means are provided to establish two-dimensional movements of the current stream in order to heat the entire butt edge surface area from inner corner edge to outer corner edge.

To effect movement of the weld current stream in two-dimension directions to cover an area, electromagnetic means, generally indicated by both magnets 36 and 71, are provided to establish proper co-operating magnetic flux fields to move the weld current stream in a predetermined path that will cause the weld current to traverse and heat the entire area presented to be welded, from inner to outer edge corners, and obviate the formation of V-shaped grooves with stress-concentration lines.

Such a system is indicated simply and schematically in the diagram of Figure 43. Energy from the alternating current circuit 10 is transformed by the transformer 9 and delivered to the electrodes 67 and 68 to be applied to the pipe 65 across the seam 66. The edges of the plate or skelp which is formed into the cylinder to be welded into a pipe, are engaged to form the cleft 69, the point of initial engagement to form the seam 66. The two electromagnets 36 and 71 are located adjacent the region of the seam extending from the cleft point to a short distance away from the cleft along the formed seam.

In order to scan and heat the entire edge surfaces at the seam, each weld current impulse should traverse the middle or central region and the top and bottom edge border regions of the seam surfaces to be welded. It will therefore be appreciated, upon reference to Figures 36, 37, and 38, that the weld current stream 30 should be reciprocated longitudinally along the seam surface 83 while the weld current stream is relatively in each zone shown in those three figures, so that the entire areas of the seam surfaces 83 will be heated and welded.

The weld current stream in the system of Figure 43 is therefore controlled, for example, so that while the weld current stream 30 is positive, as in Figures 19, 20, 21, 35, 36, 37 and 38, magnet 36 will be energized by the first positive control frequency wave to shift the weld current stream to the left, as in Figure 20, but the magnet 71 will remain unenergized so the weld stream 30 will move and remain substantially centrally located along the middle longitudinal zone of the seam surface 83, as in Figure 36, due to the balancing and centralizing effect of the flux around the weld current stream when no control flux is present from the magnet 71 to affect the position of the weld current stream 30 up or down vertically.

Thus, during the time of the first positive impulse 39–*a* of the control frequency current of Figure 26, while the weld current is positive, magnet 36 is energized as in Figure 20, and magnet 71 is unenergized as in Figure 36.

During the next time interval, represented by the negative impulse 39–*b* of the control frequency current, while the weld current is still positive, magnet 36 is energized as in Figure 21 and magnet 71 is energized as in Figure 37. Under those conditions the weld current stream is forced to the upper zone along edge 82 of the seam surface 83, and is moved to the right to traverse and heat that upper zone along the seam surface 83 for the distance controlled by the control magnets.

When the control frequency current changes polarity again to positive impulse 39–*c*, while the weld current is still positive, as in Figure 26, magnet 36 becomes energized as in Figure 20 again, and magnet 71 is energized as in Figure 38. Under those conditions the weld current stream 30 is forced to the lower zone along lower edge 84 of the seam surface 83, and is moved to the left to traverse and heat that lower zone along the distance controlled by the control magnets, back to the seam cleft.

When the weld current polarity changes to negative, as in Figure 26, the three impulses of the control frequency are made to control the movement of the weld current

Plaintiff's Exhibit PX-1

stream in the same manner as was described during the positive welding current wave.

During the first negative control frequency impulse 39–*d*, while the weld current is negative, magnet 36 is energized as in Figure 24, but magnet 71 is not energized, as shown in Figure 40. The weld current stream 30 is moved to the left to the cleft. Since magnet 71 is not energized the weld current stream is maintained along the middle zone of the seam surface 83.

When the control frequency current changes polarity to positive 39–*e*, being then the second impulse, while the weld current is negative, magnet 36 is energized as in Figure 25 and magnet 71 is energized as in Figure 41. Under those conditions the weld current stream is forced to the upper zone along edge 88 of the seam surface 83, and is moved to traverse and heat that upper zone along the seam surface 83 for the distance controlled by the control magnets.

While the weld current is still negative, and the control frequency polarity changes back to negative, the third control impulse 39–*f*, as shown in Figure 26, magnet 36 is energized as in Figure 24 and magnet 71 is energized as in Figure 42. Under those conditions the weld current stream is forced to the lower zone along edge 84 of the seam surface 83, and is moved to the left to the cleft, thereby heating and welding the seam surfaces along the lower zones or corners.

Thus, during each welding current wave of each polarity, the weld current stream is first moved along the central zones of the seam surfaces to the cleft for the duration of the first control frequency impulse; then raised to the upper edge and moved to the right for the duration of the second control frequency impulse; and is then depressed to the lower edges of the seam surfaces and moved back to the left to the cleft for the duration of the third control frequency impulse.

The above sequence of operations continues for each cycle of weld current voltage, and assures, by such scanning action, a complete heating and welding of the edge surfaces presented to form the seam. By the action of forcing the weld current stream upward toward and against the upper corner edges, the formation of an unwelded V-shaped groove along the edges is prevented.

The V-shaped groove, initially formed by the weld current stream moving along the middle of the seam surfaces, is in effect a cleft running longitudinally along the seam, and constitutes a region of high resistance that is conducive to the development of a large amount of heat to assure a complete effective weld along the edge of the seam, and thereby obviate any V-shaped groove to constitute a line of high stress concentration.

Similarly, the V-shaped groove is prevented at the lower edge of the seam, so the entire seam surfaces are entirely welded from edge to edge.

In order to control the energization of the control magnets 36 and 71 of the system in Figure 43, to establish the sequence of control operations as outlined above, the electro-magnet 36 may be connected to be energized continuously by the triple-frequency control current, since the three control impulses will move the weld current stream of each current wave of each polarity in a complete sequence in a path, insuring a complete welding action between the seam surfaces.

In the case of the magnet 71, however, the first of the three control impulses, for each current wave of each polarity, is not used, in the system herein described. The second control impulse is used to drive the weld current stream to the upper edge; and the third control impulse is used to drive the weld current stream to the lower edge.

In order to establish such selective action in supplying only the second and the third control impulses to magnet 71, a system such as shown in Figure 43, or its equivalent, may be employed.

Two coils 88 and 89 are provided to energize magnet 71, and are arranged to be reversely effective. A source 90 of triple welding frequency is connected to the coils 88 and 89 through two grid-controlled gas-filled rectifier selector tubes 91 and 92, respectively.

The two selector tubes 91 and 92 are controlled to transmit the desired control impulses of proper polarity, according to the sequence outlined above, by a synchronously operated impulsing device 93 that impresses voltage upon the grids of the tubes 91 and 92 to transmit the control impulse of proper polarity at the right time to move the weld current stream in the desired direction.

The selector tubes 91 and 92 are gas-filled tubes that are rendered conductive when the cathode is negative to the anode and the grid slightly positive relative to the cathode, even though only momentarily. If the grid is negative relative to the cathode, the tube will not become conductive, even though the relative polarities of the cathode and of the anode are proper.

In order to block the selector tubes 91 and 92 against improper operation, the grids of the two tubes are normally biased slightly negative to their associated cathodes by a bias voltage, such as derived from a battery 94, applied to a balanced circuit including resistors 95 and 96 connected to the tube grids.

The selector tubes 91 and 92 are selectively rendered conductive, against the biasing voltage, by an operating voltage applied to the grids by the impulsing device 93. That device comprises a synchronous motor 97 driving a disc 98, with two pins 101 and 102, on opposite sides of the disc, to control the magnetic circuits of two impulsing transformers 103 and 104, to generate the impulsing operating voltages to be applied to the grids of the tubes 91 and 92.

Each impulsing transformer 103 and 104 consists of the core structure 105, a primary winding 106, and a secondary winding 107. A source of direct current 108 energizes the primary windings. The secondary windings are respectively connected to the grids of the two selector tubes 91 and 92. The core structure 105 has a gap, through which one of the pins on the disc will pass with each rotation of the disc. When the pin is in the gap, the reluctance of the core changes, and the resultant increase and decrease in the magnetic flux, due to the energization of the primary winding, induces a sharp peaked voltage in the secondary winding. That secondary peaked voltage momentarily overbalances the bias voltage and energizes the grid of the corresponding tube while the polarity of the control voltage is such as to render that tube conductive.

The two pins 101 and 102 are spaced apart one-third of the angular distance around the disc, and they are equally spaced from a zero starting point 110 on the disc. The zero point 110 on the disc should correspond in mechanical position to the electrical zero point of the control wave 39–*a* in Figure 26. The pin 101 should reach the gap of the core of impulsing transformer 103 at the zero point at the beginning of the negative wave 39–*b*, the second wave during the positive weld current wave. The pin 102 should reach the gap in the core of the impulsing transformer 104 at the zero point at the beginning of the positive wave 39–*e*, the third control frequency wave while the weld current is positive.

Thus, the impulsing device 93 will not operate during the interval of the first control frequency wave related to each weld current wave, so the selector tubes 91 and 92 will be blocked against conduction by the biasing voltage on the grids. During the second and third control frequency waves related to each weld current wave, the impulsing device sequentially energizes the grids, and renders the tubes sequentially conductive, to transmit the corresponding current waves of the control frequency, to sequentially energize the windings 88 and 89 of the magnet 71, to establish the flux in the magnet 71 in

the desired directions to force the weld current stream to the seam surface edges, as previously explained.

The synchronous motor 97 of the impulsing device 93 is shown connected to the triple-frequency source 90. It may alternatively, be connected to the fundamental welding current source, so long as the proper relation is first established between the position of the mechanical zero point 110 of the disc and the starting electrical zero point of the weld current and of the multiple-frequency control current. For insuring such mechanical and electrical synchronism, any suitable system may be employed for that purpose, such as shown, for example, in U.S. Patent No. 1,724,650 of Harold E. Fox, issued August 13, 1929.

For the purpose of illustration, the foregoing system of control is described as applied to a butt weld between two metal elements, shown here as the seam edges of thin-wall tube, and also between two thick metal sections which may be the seam edges of a thick-wall tube or pipe.

The system is similarly applicable to a lap weld with a narrow contact zone, except that the control magnet should be located to dispose the flux at right angles to the normal path, or direction of flow, of the weld current stream, between the two associated electrodes that carry the welding current. If the lap contact zone is narrow enough to be covered, in its width, by the weld spot of the progressively moving weld current stream, simple reverse or sweeping of the weld current stream back and forth on the lap area is sufficient to effect a complete weld over the entire lap area.

Where the lap contact zone is wider than the width of the weld spot formed by the weld current stream, the weld current stream should be controlled as in the case of the butt weld between thick walls, to have both a sweeping and a swinging action, through a path that will cause the weld current stream to traverse the entire surface area that is to be welded, thereby to heat that entire area to welding condition. Where the surfaces lap instead of butt, the magnetic control flux should be properly disposed to establish the control action to move the weld current stream as described, in the desired path to scan the area to be welded.

In Figures 44 to 50, is shown the manner in which a current stream is caused to scan a surface area to be welded, by a combined sweeping and swinging action of the current stream. The two inner directional symbols indicate that the same action takes place for the weld waves of both polarities.

In Figure 44, the circle 111 represents the weld current stream in the plane of the electrodes, and centrally between the upper and the lower edges of the seam surface.

In its position 112 in Figure 45, the weld current stream has been swept to the seam cleft, during the first control interval, corresponding to the time of control wave 39–*a*.

In Figure 46, the weld current stream has been swung upward to position 113, at the upper edge of the seam surfaces, for the beginning of control interval 39–*b*.

In Figure 47, the weld current stream has been swept along the upper edge through interval 39–*b*, to the right to position 114, which represents the right-hand extremity of its sweep movement, at the end of control interval 39–*b*.

In Figure 48 the weld current stream has been swung down to position 115, at the lower edge of the seam surfaces, for the beginning of control interval 39–*c*.

In Figure 49, the weld current stream has been reciprocated, or swept, leftwards, along the lower edges and through control intervals 39–*c*, to position 116, at the cleft. At this position the positive welding current wave diminishes to its zero value.

In Figure 50, the negative weld current wave starts at its normal intermediate position 117, corresponding exactly to the positive wave at position 111. The negative weld current wave is then controlled by its three control waves in the same manner and through a similar path as already described for the positive weld current wave in Figures 44 to 49, inclusive.

In Figure 51, is illustrated, schematically exploded, a series of weld stream paths that are progressively overlapped during the welding operation, to establish a continuous weld along every zone of the seam surfaces.

For the sake of simplifying the illustrations, the Figures 44 to 50 show merely the path of the current stream in its scanning movements, without considering the simultaneous advance of the pipe or other object being welded.

By such scanning action of the current stream, the entire seam surfaces become heated and welded. Because of the fast movement of the current stream relative to the seam surfaces, the heating and cooling action is rapid, and little time is presented for the metallurgical structure to change.

By suitably controlling and co-ordinating the pressure at the seam and the current supplied to the electrodes, according the speed of movement of the surfaces to be welded, the welding heat can be confined substantially to those surfaces, so that the metal which will be softened or melted on each surface, to intermingle and coalesce or weld, will form a relatively thin bonding layer between the metal behind the original surfaces. The layer of bonding metal, because of its relatively rapid cooling, becomes a strong fine grain structure.

The distribution of the heating effect of the current stream provides an equalized uniform heating condition comparable to direct current heating, and yet permits the use of alternating current with its attendant simplicity and flexibility of control.

A further result is the formation of a continuous weld over the entire surfaces without any unwelded areas or stress concentration zones.

The rapid heating and cooling action confines the heat generation to the seam surfaces and does not provide time for the heat to penetrate back into the body of the metal to form weakened side zones along the seam.

As previously mentioned, the desirable theoretical effects and benefits of a high frequency welding current are normally not procurable, because of the reactive impedances developed in a circuit by such high frequency current. Those effects and benefits are procurable, however, with the system disclosed herein, through the use of a multiple frequency or high frequency current for control uses only, instead of for the actual welding operation. The quantity of current required for the control action is considerably smaller than the welding current, and the impedance to the control current is sufficiently small to permit an effective control current to traverse its circuit.

For convenience and simplicity the control frequency is shown and adopted as a multiple of the fundamental welding current frequency, and preferably derived as a function of the fundamental frequency to simplify the problem of synchronizing the control current impulses with the weld current impulses to establish the desired control relationship.

The matter of phase relationship between the welding current and the control current has been assumed, in the foregoing description, to be as illustrated, with both currents in phase to the extent that zero points of both current waves are synchronous.

Since the heating effect is independent of the character of the current, that is, whether it is alterating or direct, the control system shown and described herein may be employed with direct welding current instead of with alternating current as shown herein. The advantages of the high speed welding operation are similarly achieved with direct welding current when so controlled. In that case any suitable control frequency may be employed, as desired.

The forming mechanism 3 of Figure 1 may be of any suitable construction that will form the strip progressively into a continuous cylinder. The side pres-

sure rolls 11 and 12 should be adjustably mounted to permit their relative spacing and their side pressures against the tube or pipe to be adjustably varied.

The sweep magnet 36 for reciprocating the welding current has been illustrated merely as a simple structure having its pole pieces adjacent the electrode gap or plane. The extent of the pole piece dimension along the length of the seam, adjacent the electrodes, will govern the extent of the sweep of the weld current stream. The pole pieces may therefore be proportioned according to the length of the desired sweep movement.

An extension of the principle of the sweep magnet is illustrated in the modified magnet 45 of Figure 27, as an example of a means for establishing a travelling magnetic control flux field to sweep the welding current stream back and forth along the seam surfaces to be welded.

The control frequency generator 38, as previously explained, has been shown, for simplicity and by way of example, as a transformer arrangement to provide a third harmonic voltage having a frequency three times that of the fundamental frequency of the welding circuit. Other frequency generators, functionally equivalent, might equally well be employed, and other control frequencies may be employed, suitable for the requirements of the particular application to which the welding operation is applied.

In considering and explaining the positive control imposed upon the weld current stream by the control magnets, any incidental shifting of the current stream, of the kind illustrated in Figures 14, 15 and 16, have been disregarded, since the imposed control is not affected in its operation by such incidental shifting of the weld current stream.

In the general control system of Figure 43, only one type of control is shown, in which all of the control current is employed, or in which only selected impulses are taken and utilized for control purposes.

Other changes and modifications of the control system may be made, according to the requirements of the application where the welding operation is to be utilized, without departing from the spirit and scope of the invention, as set forth in the appended claims.

What is claimed is:

1. The method of electrically welding two engaging pieces of metal at their surfaces of engagement, which consists in passing an electric welding current substantially normal or perpendicular to and through the engaging weld surfaces, and establishing an electromagnetic flux field adjacent the zone of the weld current stream, the current and the flux field being so related that at least one is alternating with the flux field being disposed at such angle relative to the weld current stream and of such polarity relative to that of the weld current as to establish an electro-dynamic action on the weld current stream to cause the weld current to move and to scan the surfaces to be welded.

2. The method of electrically welding two engaging pieces of metal at their surfaces of engagement, which consists in passing an electric welding current substantially normal or perpendicular to and through the engaging weld surfaces, and establishing an electromagnetic flux field adjacent the zone of the weld current stream, with the flux field of such polarity and at such angle relative to the weld current stream as to establish an electro-dynamic action on the weld current stream to cause the weld current to shift its flow section or impingement area back and forth on the weld surfaces to progressively heat those surfaces as traversed by the current stream, the current and the flux field being so related that one is alternating.

3. The method of electrically welding two engaging pieces of metal at their surfaces of engagement, which consists in passing an electric welding current substantially normal or perpendicular to and through the engaging weld surfaces, and establishing an electromagnetic flux field adjacent the zone of the weld current stream with the flux field of such polarity and at such angle relative to the weld current stream as to establish an electro-dynamic action on the weld current stream to cause the weld current to shift its flow section to sweep the weld surfaces in a path having longitudinal and lateral directions, to progressively heat the entire engaged surface areas, the current and the flux field being so related that at least one is alternating.

4. The method of electrically welding two engaging pieces of metal at their surfaces of engagement, which consists in passing an electric welding current substantially normal or perpendicular to and through the engaging weld surfaces, and establishing an electromagnetic flux field, of greater frequency than the weld current, adjacent the zone of the weld current stream and at such angle relative to the weld current stream as to establish an electro-dynamic action on the weld current stream to cause the weld current to move and to scan the surfaces to be welded.

5. A method of manufacturing welded tubing or pipe from strip or skelp, which consists in folding the strip or skelp into cylindrical form to engage the seam edges progressively into butting contact, passing an electric welding current across the seam, in the region of the progressively butting contact, and setting up an alternating magnetic flux control field in that region of the path of the welding current stream, the magnetic flux control field being disposed physically and angularly relative to the current stream to establish an electro-dynamic action between the control flux field and the flux field of the weld current to cause the current stream to reciprocate longitudinally of the seam in the region of the progressive contact.

6. A method of manufacturing welded pipe from strip or skelp, which consists in folding the strip or skelp into cylindrical form to engage the seam edges progressively into butting contact, passing an electric welding current across the seam at one frequency in the region of the progressively butting contact, and in setting up an alternating magnetic flux control field of a higher frequency adjacent the path of the welding current stream, with such control field of proper polarity, duration, and angular disposition relative to the weld current, to react electro-dynamically on the weld current, and to cause the weld current to scan the surfaces progressively engaging at the seam.

7. The method of electrically welding two engaging pieces of metal at their surfaces of engagement, which consists in passing an electric welding current substantially normal or perpendicular to and through the engaging weld surfaces, and establishing an electro-magnetic flux field, adjacent the zone of the weld current stream and at such angle relative to the weld current stream as to establish an electro-dynamic action on the weld current stream to cause the weld current to move and to scan the surfaces to be welded, and selectively controlling the polarity and duration of the flux field according to the direction of flow of the weld current, in order to control the duration and direction of the electro-dynamic forces acting upon the weld current stream.

8. Welding apparatus for welding two metal parts, comprising an electrode to engage each part; a source of welding current connected to the electrodes, the electrodes being disposed to engage the parts on opposite sides of the weld surfaces so the current will cross from one weld surface to the other; electro-magnetic means for establishing magnetic flux control fields adjacent the weld zone and the path available in that zone for the weld current so the flux field will react electro-dynamically on the weld current stream; and means for controlling the energization of the electro-magnetic means to control the duration, the timing and the polarity of the control fields to govern the electro-dynamic reaction between

the fields and the weld current and thereby govern the design of a path of movement of the weld current section along the weld surfaces.

9. Welding apparatus for progressive seam welding between two metal elements, comprising an electrode for engaging each element on opposite sides of the seam to be welded, so the weld current between the electrodes will pass through the surfaces from one surface to the other; a source of welding current connected to the electrodes; electro-magnetic means for establishing a magnetic flux control field adjacent the weld zone and the path available in that zone for the weld current so the flux field will react electro-dynamically on the weld current stream, to cause the weld current stream to scan the weld surfaces; a source of energy for the electro-magnetic means; and means for selectively controlling the transfer of energy to said electro-magnetic means including electric valve means, and timing means for controlling the valves to render them conductive for selected intervals.

10. The method of electric resistance welding, which consists in passing a welding current between two surfaces to be welded, and in setting up, adjacent the adjoining surfaces, a magnetic flux field, having two directional time components and having proper polarity and angular disposition to be electrodynamically effective relative to the welding current. thereby to establish electro-dynamic action between the flux field and the welding current stream as a movable conductor, to effect movement of the welding current stream in a path of pre-determined pattern, as controlled by the flux field form, disposition, polarity and frequency, and thereby cause the welding current stream section to sweep and scan the areas of the two surfaces in accordance with said pattern.

11. In an alternating current welding system, for welding two metallic members at pre-determined surface areas, the combination with means for supplying a welding current to the members so the current will cross between the surfaces to be welded, of electro-magnetic means, operative, when energized, to establish magnetic flux fields of predetermined polarities, and of such duration and so located, relative to the welding current stream, as to set up electro-dynamic reactions against said welding current stream, that will move the flow section of the welding current stream in a predetermined pattern, irrespective of any relative movement between the metallic members and the current-supplying means, and means for selectively controlling the energization of said electro-magnetic means for selective time intervals during the establishment of such predetermined polarities, to cause the current stream to scanningly traverse, heat and weld the surfaces along the outer or contour edges of the pre-determined weld surface areas to ensure complete welding of the surface areas.

12. In a welding system for electrically welding two metallic members at pre-determined surfaces, the combination with means for pressing the surfaces to engagement, electrodes for engaging the two members on opposite sides of the welding zone of engagement of the two surfaces to cause the current to flow from one surface to the other surface so as to impress a potential difference between the two surfaces, and means for supplying a welding current to the electrodes for transmission through the surfaces to be welded, of means independent of the welding circuit and disposed adjacent the welding zone to establish a magnetic flux field perpendicular to the normal direction of current flow, and of proper polarity and duration relative to the weld current stream, for electro-dynamically shifting the flow section of the weld current stream in a pre-determined path having a substantially longitudinal component to cause the weld current stream to flow through selected areas of the surfaces to be welded.

13. In a welding system for welding two metal elements at, and over the area of, two contacting surfaces, the method of controlling the location of the weld current stream section to cause that current stream section to scanningly traverse the surface areas, which consists in establishing an electro-magnetic control flux field adjacent the contacting surfaces, with the flux field of suitable polarity and so angularly disposed relative to the current stream as to establish an electro-dynamic reaction on the weld current, to move the current stream section is a desired longitudinal direction; and in establishing said control flux field by a current of sinusoidal form.

14. The method of resistance welding two surfaces, engaged over a longitudinal area, which consists in passing a weld current stream between and substantially perpendicularly across the two surfaces; setting up an electro-magnetic flux field perpendicularly to the current stream with the flux of proper polarity to establish an electro-magnetic reaction to force the current stream to one contour edge of the area of engagement of the two surfaces; and setting up a second electro-magnetic flux field disposed to be electro-dynamically effective to shift the current stream longitudinally along said contour edge in a desired direction.

15. The method of resistance welding two surfaces, engaged over a longitudinal area, which consists in passing a weld current stream between and substantially perpendicularly across the two surfaces; setting up an electro-magnetic flux field perpendicularly to the current stream and of proper polarity to establish an electro-magnetic reaction to force the current stream to one contour edge of the area of engagement of the two surfaces; and setting up a second electro-magnetic flux field disposed to be electro-dynamically effective to shift the current stream along said contour edge in a desired direction and to be of proper polarity and duration to shift the current stream back and forth along said contour edge.

16. The method of electrically welding two jointly moving progressively engaging metallic surfaces, which consists in passing an electric current between the two progressively engaging surfaces adjacent the progressively moving point of contact, and setting up an alternating magnetic flux field adjacent the current stream and substantially perpendicular to the current stream to cause the current stream to reciprocate longitudinally along the engaged traveling seam edges on the weld surfaces in the region where they are progressively engaged.

17. The method of electrically resistance-welding two metallic surfaces, which consists in engaging the two surfaces with a relatively light contact pressure to establish an electrical resistance across such contacting surfaces that is many times the resistance of an equal area of the body metal, passing an electric current across the contacting zone, and establishing an electro-magnetic flux control field adjacent the contacting zone, one of the said currents and the said flux field being alternating, and the flux field being so disposed angularly relative to the current stream as to set up an electro-dynamic reaction to sweep the current along the contacting zone to cause the heating time and effect of the current to be of relatively short duration, and too fast to permit an accumulated heating effect that would be sufficient to cause melting and dropping out of the metal.

18 The method of electric resistance-welding, which consists in passing an electric current substantially at right angles to and between two surfaces to be welded, and in setting up a separate electro-magnetic flux control field to electro-magnetically control the welding current to cause the current stream to move so its impingement area on the weld surfaces will revolve in a path closing upon itself on the weld surfaces, the welding current and the flux control field being so related that one is alternating, and the flux field is angularly disposed to the path of the current stream between the two surfaces.

19. Welding apparatus for electric resistance-welding, comprising means for supporting two metallic members

to hold their surfaces in position as they are to be welded, electrodes for engaging the metallic members to conduct the welding current thereto, a source of energy connected to the electrodes, electro-magnetic means adjacent the welding surfaces and the electrodes to establish a magnetic control flux adjacent to and substantially at right angles to the current stream to move the welding current stream through a predetermined path in the weld zone, and means for energizing the electro-magnetic means to establish a control flux of proper polarity to move the welding current in a desired path over an area in the weld zone to scan the weld surfaces in that weld zone.

20. A system for progressively welding two metallic members along selected surface areas, comprising means for engaging the areas of the two surfaces in the position at which they are to be welded, electrode means to be applied to the metallic members to transmit welding current to the two members to cross the areas of the plane of engagement of the engaging surfaces, a source of welding energy connected to the electrodes, electro-magnetic means adjacent the current path between the electrodes to set up a magnetic flux field substantially perpendicular to the weld current to establish an electro-dynamic action to shift the flow section of the welding current stream in said path between the electrodes, a source of alternating polarity energy for the electro-magnetic means to enable said means to set up a field to effect movement of the flow section of the weld current stream in one pair of opposite directions in the plane of the weld surfaces, and second electro-magnetic means to set up a flux to move the current stream in a second dimensional direction in said plane, and a source of energy for said second electro-magnetic means.

21. A system for progressively welding two metallic members along selected surface areas, comprising means for engaging the areas of the two surfaces in the position at which they are to be welded, electrode means to be applied to the metallic members to transmit welding current to the two members to cross through the engaging areas of said surfaces, a source of welding energy connected to the electrodes, electro-magnetic means adjacent the current path between the electrodes to set up a magnetic flux field to shift the welding current stream, a source of energy of alternating polarity for the electro-magnetic means to enable said means to effect movement of the flow section of the weld current stream in one set of opposite directions in the plane of the weld surfaces, and second electro-magnetic means to set up a flux to move the current stream in a second dimensional direction in said weld plane, a source of alternating polarity energy for the second electro-magnetic means, and means for selectively supplying energy impulses of selected polarity to both the electro-magnetic means in predetermined time sequence.

22. The method of welding two metallic members at and along predetermined engaging surface areas, which comprises transmitting a welding current across the two members and through said surfaces, and simultaneously establishing an electro-magnetic flux field adjacent said surface areas and the stream of the welding current, the current and the flux being so related that at least one is alternating, with the flux field disposed perpendicularly to the weld current stream and in such position tangentially relative to the current stream and in such magnetic direction relative to the current direction, as to shift the weld current stream to move its flow section through a path of predetermined pattern laterally in the plane of the engaging surface areas, to cause the weld current stream to traverse and heat the entire areas of the surfaces to be welded.

23. The method of welding two metallic members at and over predetermined surface areas of engagement between the two members, which comprises moving said surface areas progressively into engagement of relatively high electrical resistance; passing an electric welding current substantially normal or perpendicular to and through the engaging weld surfaces of sufficient amplitude relative to the high resistance of engagement to effect melting of a thin surface layer of and at the engaging surface areas; and establishing an electro-magnetic flux field adjacent the zone of the weld current stream and so disposed relative to the magnetic flux of the welding current stream as to cause an electro-dynamic action on the weld current stream to cause the weld current to move and scan the weld surfaces at a speed faster than the rate of progressive surface engagement, whereby the weld surfaces will be subjected to a fast high heating effect and a subsequent fast cooling effect, that will establish a strong weld characterized by a fine grain bonding layer resulting from the thin layer of molten metal being quickly cooled.

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TUBE WELDING

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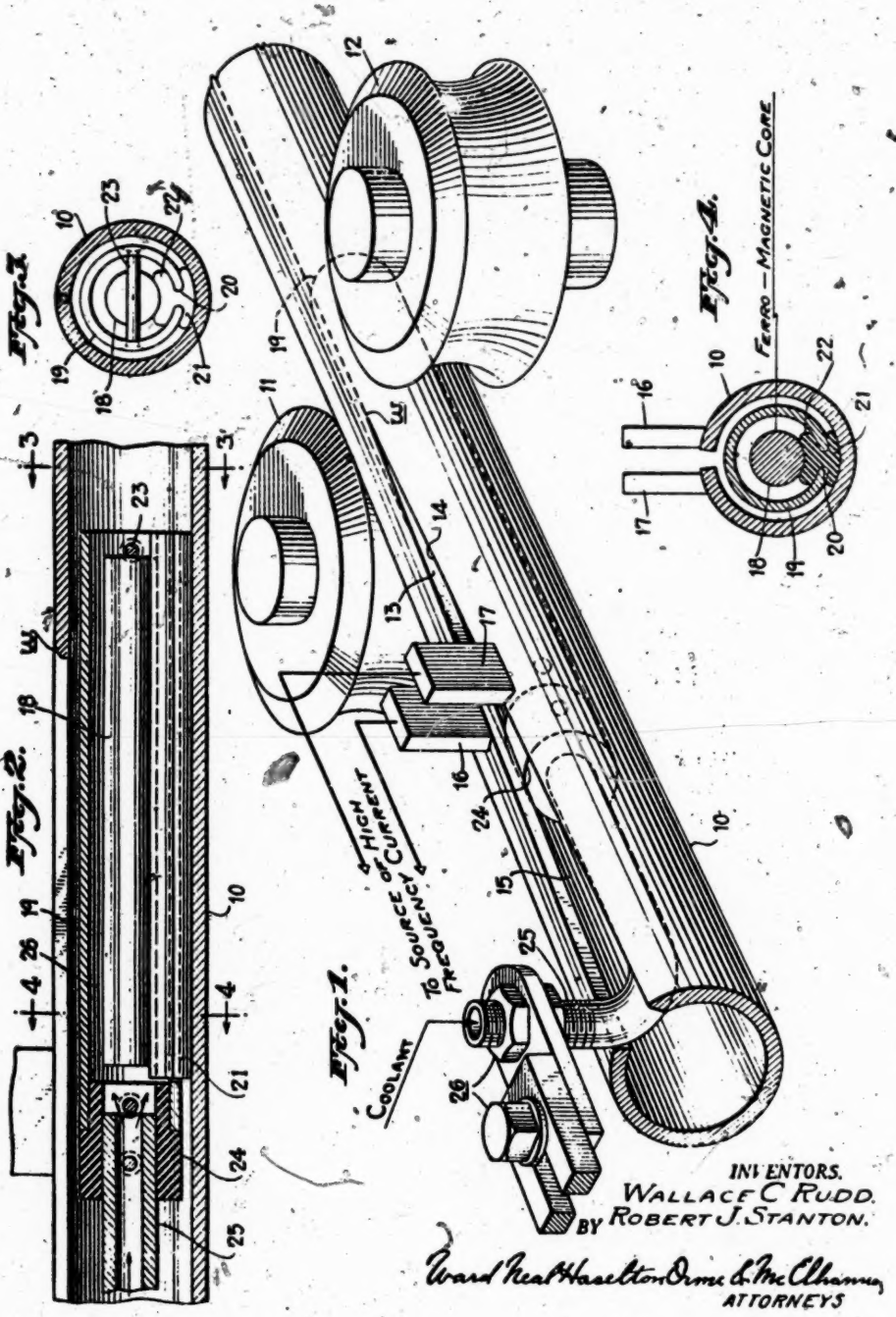

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TUBE WELDING

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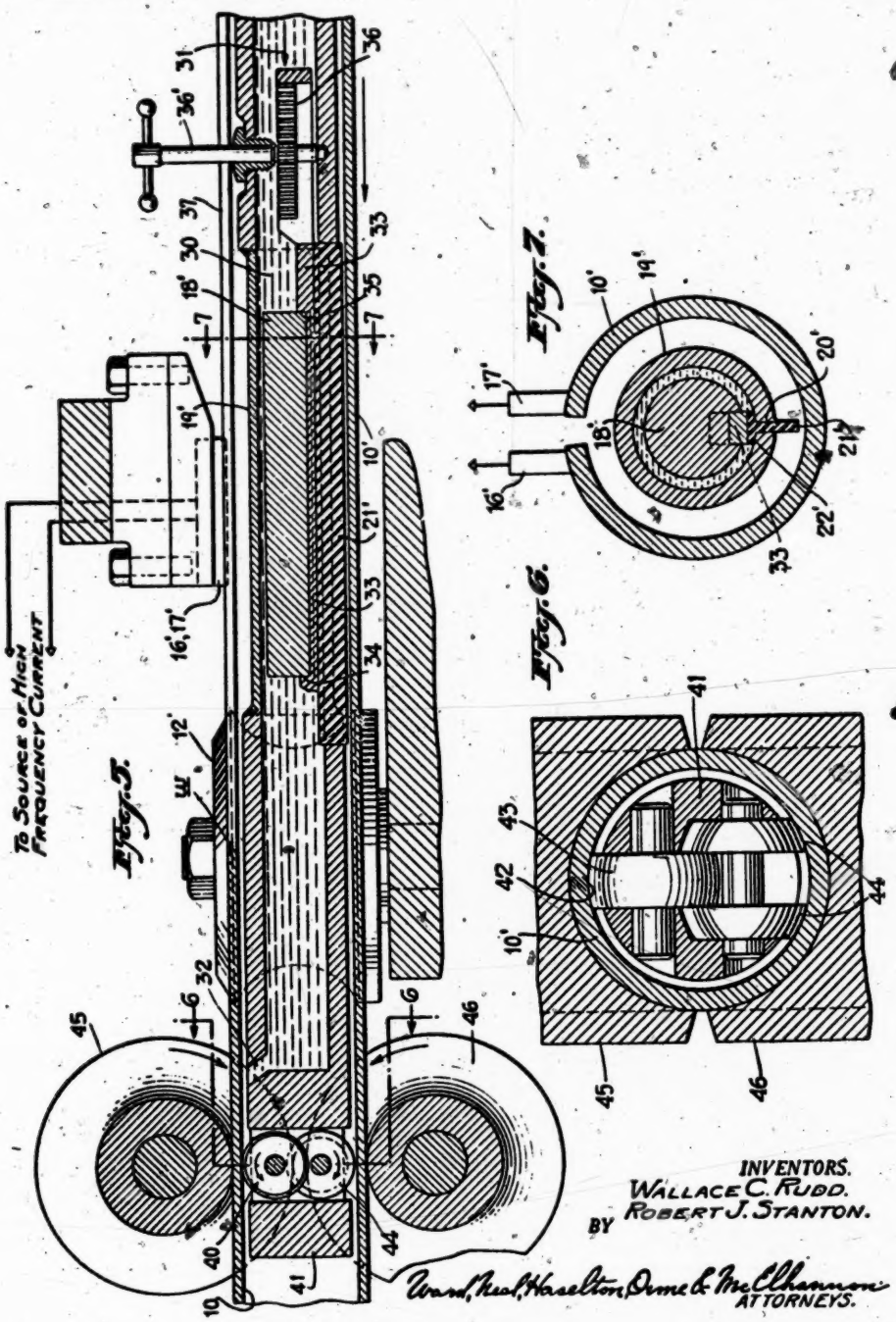

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TUBE WELDING

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Application March 14, 1956, Serial No. 592,702

9 Claims. (Cl. 219—59)

This invention relates to methods and apparatus for welding by the use of high frequency electrical heating and more particularly among other possible uses for continuously welding a longitudinal seam in metal tubing.

Reference is made to the co-pending application of Wallace C. Rudd and Robert J. Stanton, Serial No. 421,768, filed April 8, 1954, and to their preceding application Serial No. 332,422, filed January 21, 1953 (now abandoned), the subject matter of said applications being disclosed also in Belgian Patent No. 530,877, granted August 31, 1954. Said applications and said patent disclose a method and means for welding together the edges defining the longitudinal gap in metal tubing as the tubing is advanced longitudinally while applying pressure thereto to close said gap at a weld point. According to said method, the heating of the gap edges is effected by the use of electrodes connected to an oscillatory current source and applied respectively adjacent the gap edges at points positioned shortly in advance of the welding point, the current being of a frequency sufficiently high so that the lowest impedance path between the electrodes follows said gap edges to and from the weld point. The present invention involves improvements upon the features of such method and apparatus.

As pointed out in our above-mentioned prior disclosures, in some cases, particularly if the tube diameter is relatively small, there will, however, be a tendency for at least some part of the current to flow circumferentially around the tube instead of along the edges of the V-shaped gap and there may be a tendency for the weld point to vary its position along the direction of travel of the tube with consequent loss of efficiency and irregularities in the weld. As further pointed out in said prior disclosures, these difficulties may be minimized by increasing the impedance of the current path from one of the contacts circumferentially around the tubing to the other, by mounting within the tubing or adjacent thereto magnetic core means or the like, with the result that this increased impedance of this path causes the radio high frequency current still further to be concentrated where it is desired along the V-shaped gap edges and also the position of the small arc which occurs at the weld point becomes more dependably stabilized at a fixed point. The possible speed of welding of the tubing may therefore be greatly increased and the quality and uniformity of the weld may be improved.

As we have heretofore disclosed, the magnetic core means used is preferably comprised for example of rods of sintered magnetic oxide insulation material, of known types which have a low loss factor, high volume resistivity, and a permeability preferably substantially greater than unity, for example such as the material marketed under the trade name "Ferramic" by General Ceramics & Steatite Corp. This material is a non-electrical conductor and has a Curie point in the range of about 200° to 300° F. However, since the heated tube edges and the arc at the weld point will come very close to such material, particularly if the tube diameter is small, sufficient radiant

heat may reach such core material either to cause same to crack or to raise its temperature above the Curie point temperature, so that it ceases properly to function.

However, in accordance with the present invention, we have found that these problems may be satisfactorily overcome by surrounding the magnetic core material by suitable container means such as copper tubing, which in turn is mounted within the advancing tube being welded and which container means also preferably is arranged to be continuously fluid cooled.

Various further and more specific objects, features and advantages of the invention will appear from the description given below, taken in connection with the accompanying drawings, illustrating by way of example certain preferred forms of the invention.

In the drawings:

Fig. 1 is a somewhat schematic perspective view of one form of the invention;

Fig. 2 is a longitudinal sectional view taken on a vertical plane through the arrangement of Fig. 1;

Figs. 3 and 4 respectively are transverse sectional views taken substantially along lines 3—3 and 4—4 of Fig. 2;

Fig. 5 is a longitudinal sectional view of an alternative arrangement of apparatus embodying the invention; and

Figs. 6 and 7 respectively are transverse sectional views taken substantially along lines 6—6 and 7—7 of Fig. 5.

Referring to the drawings in further detail, the tube which is to be welded is indicated at 10 advancing in the direction of the arrow shown through a tube mill which may include a pair of pressure applying rollers as at 11 and 12 which engage opposite sides of the tubing near the region of the weld point w and so that the opposite edges 13 and 14 within the V-shaped gap 15 are firmly brought together. The contacts or electrodes by which the radio frequency current is applied to the gap edges are indicated at 16 and 17, these preferably being fluid-cooled as shown in the above-mentioned previous disclosures and being located slidably to engage at or adjacent the gap edges a suitable distance in advance of the weld point. As disclosed in our said application Serial No. 421,768, the frequency of the current used preferably is of the order of 100,000 cycles per second or higher, for example 300,000 to 500,000.

While with the apparatus as shown in Fig. 1, the V-shaped gap in the tubing is indicated as extending along the upper side of the tubing, it will be understood that this is for convenience of showing only and that the gap might be at other places, either at one side or along the bottom of the tubing, and in construing the appended claims, such other possibilities should be considered as coming within the scope of the invention.

Referring now to the drawings in further detail, one of the rods of magnetic core material is indicated at 18 mounted within a tubular metal container as at 19 for example, formed of copper tubing and being preferably, although not necessarily, slitted along one side as at 20 to prevent the circumferential flow of high frequency induced current therein. The tube 19 may rest upon a strip of suitable insulation material as at 21, and if the tube is slit, such insulation material may, as shown, extend up through the slot and be shaped also to provide a support 22 for and extending along beneath the core rod 18. Suitable means such as a pin 23 may extend through the end of the container 19 for preventing the core rod from sliding out.

As best shown in Fig. 2, the left hand end of the container 19 may comprise a suitable insulation connecting member 24, which brings a conduit 25 for cooling fluid into communication with the container 19. The conduit 25 may, as shown in Fig. 1, constitute a support for the rod of magnetic core material and its container. As further indicated in Fig. 1, the conduit 25 may be carried

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by a suitable adjustable supporting bracket means as at 26, permitting adjustment of the position of the core and its container both longitudinally of the tubing 10, as well as vertically with respect to the gap 15.

Cooling fluid such as water may be supplied to the conduit 25 to flow therethrough and through the container 19 in the clearance space 26 therein provided around the rod 18 and thence out of the right hand end of the container, the cooling fluid therefrom being carried away in the tubing 10. Thus the rod of magnetic core material 18, as well as its container 19, are kept from being damaged by overheating and there will accordingly be no danger that the core material will reach or exceed the Curie point during continuous operation of the apparatus. It has been found that the use of such core material with this method of high frequency resistance welding is quite important for successfully welding tubing of relatively small diameters and makes possible for example the easy, uniform and dependable welding of aluminum tubing of diameters as small as 5/8" for example and at speeds in the range of from 200 to 400 feet per minute. So far as known, it has not heretofore been possible to weld small tubing of this nature by any comparable methods or at speeds even approaching such rapidity.

With the above-described apparatus, one may readily control the amount of heat at the weld point by moving the magnetic core longitudinally with respect to the position of the contacts and the welding point. Furthermore, by placement and positioning of the core, one may readily control the amount of internal upset of metal at the weld in the tubing being welded. That is, assuming that the metal has some substantial thickness along the edges to be welded, and if the current is "crowded" up to a position to flow more along the upper portion of said edge than along the lower portion nearest the inside of the tube, then the upper portion will be heated and thus softened somewhat more than the lower portion of the edge and the upset on the welded seam will tend to be more along the outer or upper side of the welded seam than internally of the tube. It will be apparent that such upward crowding of the current path may be accomplished by bringing the magnetic core body up closer to the line of the desired welded seam, thereby increasing the reactance of the high frequency current paths along the lower portion of the thickness of the metal at the gap. The most desirable adjustment of the position of the core in this respect may vary for tubing of different metals and of different thicknesses and may be determined by trial. On thin-walled steel tubing in particular, the invention makes possible a complete weld of the opposed gap surface edges without causing any broad heat pattern along such edges.

The embodiment of the invention shown in Fig. 5 provides an arrangement having the advantages of the above-described embodiment and at the same time also permitting adjustment of the longitudinal position of the magnetic core element while retaining the supporting means therefor in stationary position and at the same time utilizing such supporting means further on beyond the weld point in the tube for retaining scarfing means in position in the tube to smooth out any irregularities about the underside of the weld.

Thus in Fig. 5 the tube indicated at 10 and 10' is shown being longitudinally advanced in the same way as the tube 10 of Fig. 1. One of the two pressure rollers is here shown at 12', the weld point is indicated at w and the high frequency contacts are indicated at 16', 17'. The ferromagnetic core element is indicated at 18' within a container 19' which extends back to a suitable point of support (not shown) at the right hand side of Fig. 5. This container 19' may be formed of non-magnetic metal such as copper or stainless steel and has an internal cavity as at 30 adapted to receive a flow of cooling fluid coming in from a suitable source and running in the direction of the arrow indicated at 31. Such cooling fluid passes on in the cavity 30 to the left hand end thereof and may escape as through an outlet 32 and thence on beyond into the tube 10'.

As best shown in Fig. 7, the container tube 19' along one side may be slit and the slit filled with an insulating strip such as of nylon as indicated at 21', thereby preventing circumferential flow of induced currents around in the portions of the container tube 19' in the general vicinity of the contacts 16', 17'. As indicated the upper side of the strip 21' may be formed with a supporting area 22' upon which a carriage member 33 for the magnetic core element is adapted slidably to be supported. The carriage member 33 may be formed with notches as at 34, 35 for engaging the two ends respectively of the core member 18' so that when the member 33 is slid longitudinally of the tube 10' in either direction, the core member will be adjusted accordingly. Any suitable means may be provided for longitudinally adjusting the carriage member 33 from the exterior of the tubing, for example rack and pinion means as indicated at 36 having a rotatable handle 36' for the pinion extending up through the V-shaped gap 37 in the tube 10'.

Referring now to the left hand end of Fig. 5 and to Fig. 6, there is here shown a roller cluster assembly generally indicated at 40 for providing scarfing means within the tubing and mounted on an extension portion 41 of the container member 19'. For example, as indicated in Fig. 6, the inner surface of the welded area 42 may be engaged by a roller 43 which is held up into position for such engagement as by a pair of lower rollers 44, so that the roller 43 will smooth out the inner surface portions of the weld. Externally at this region, the tubing may be supported as by upper and lower pressure rollers 45 and 46.

Thus with the equipment shown in Figs. 5-7, one may adjust the position of the magnetic core means as is the case with the embodiment of Fig. 1, and at the same time the container means 19' offers in effect a mandrel-like means for holding in position the scarfing means within the tubing at a desired location beyond the weld point. Of course, various other forms of known scarfing means other than the roller cluster above described may be used, if desired, at the same location.

Although certain particular embodiments of the invention are herein disclosed for purposes of explanation, further modifications thereof, after study of this specification, will be apparent to those skilled in the art to which the invention pertains. Reference should accordingly be had to the appended claims in determining the scope of the invention.

What is claimed and desired to be secured by Letters Patent is:

1. Apparatus for welding together the edges of a longitudinal gap in metal tubing which comprises: means for longitudinally advancing the tubing while bringing said edges together at a weld point in a narrow V-shaped formation; a pair of contacts mounted respectively to be engaged by surfaces of the metal of the tubing along opposite sides of the gap at a position shortly in advance of said point; a source of heating current of a frequency of the order of 100,000 cycles per second or higher and having its terminals connected to said contacts respectively, whereby such current will follow a path from one of said contacts along one edge of the gap to said welding point and back along the opposite edge of the gap to the other contact; core means and means for mounting same inside the tubing for increasing the reactance of current paths extending between said contacts circumferentially of the tubing, such core means comprising a ferromagnetic but substantially an insulating mass extending along below the region of said V-shaped formation; tubular means mounted in conjunction with said core means and providing a container therefor; and means for providing a flow of cooling fluid through said container for main-

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taining said core means at a temperature below its Curie point.

2. Apparatus in accordance with claim 1 and in which supporting means for said core means and its container is provided which extends back to the side of the contacts opposite from the weld point and which supporting means includes parts permitting adjustment of the position of the core means with respect to said V-shaped formation.

3. Apparatus in accordance with claim 1 and in which the containing means for the core means comprises a length of metal tubing formed with a slit along one side to prevent the free flow in circumferential directions therein of high frequency current induced therein.

4. Apparatus in accordance with claim 1 and in which the containing means for the core means is supported on a conduit extending into the tubing for conducting the cooling fluid into the containing means.

5. Apparatus for welding together the edges of a longitudinal gap in metal tubing which comprises: means for longitudinally advancing the tubing while bringing said edges together at a weld point in a narrow V-shaped formation; a pair of contacts mounted respectively to be engaged by surfaces of the metal of the tubing along opposite sides of the gap at a position shortly in advance of said point; means for connecting the terminals of a source of radio frequency heating current respectively to said contacts; means formed of magnetic core material positioned inside the tubing at a region near the approaching gap edges and said weld point, such material acting to increase the reactance of the paths of current flow between the contacts in directions around the tubing and to thereby increase the current flow along the tube edges at the V-shaped gap to and from the weld point; carriage means for supporting said core material within the tubing; means accessible from the outside of the tubing for longitudinally adjusting said carriage means and the core material thereon; a container in the tubing for supporting said carriage means and core material; and means for connecting said container to a supply of cooling fluid for running therethrough.

6. Apparatus for welding together the edges of a longitudinal gap in metal tubing which comprises: means for longitudinally advancing the tubing while bringing said edges together at a weld point in a narrow V-shaped formation; a pair of contacts mounted respectively to be engaged by surfaces of the metal of the tubing along opposite sides of the gap at a position shortly in advance of said point; means for connecting the terminals of a source of radio frequency heating current respectively to said contacts; means formed of magnetic core material positioned inside the tubing at a region near the approaching gap edges and said weld point, such material acting

to increase the reactance of the paths of current flow between the contacts in directions around the tubing and to thereby increase the current flow along the tube edges at the V-shaped gap to and from the weld point; mandrel-like means within the tubing for supporting said core material; means for longitudinally adjusting the relative positions of said mandrel-like means and core material, said mandrel-like means extending beyond the weld point in the tubing; and scarfing means in the tubing mounted on such extension of the mandrel-like means.

7. Apparatus in accordance with claim 6 and in which said mandrel-like means has a longitudinal cavity connected to a source of cooling fluid for running therethrough.

8. Apparatus in accordance with claim 1 and in which said container comprises insulation material precluding induction in said container from said source of high frequency currents surrounding said core means.

9. Apparatus for welding together the edges of a longitudinal gap in metal tubing which comprises: means for longitudinally advancing the tubing while bringing said edges together at a weld point in a narrow V-shaped formation; a pair of contacts mounted respectively to be engaged by surfaces of the metal of the tubing along opposite sides of the gap at a position shortly in advance of said point; a source of heating current of a frequency of the order of 100,000 cycles per second or higher and having its terminals connected to said contacts respectively, whereby such current will follow a path from one of said contacts along one edge of the gap to said welding point and back along the opposite edge of the gap to the other contact; core means and means for mounting same inside the tubing for increasing the reactance of current paths extending between said contacts circumferentially of the tubing, such core means comprising a ferromagnetic but substantially an insulating mass extending along below the region of said V-shaped formation; scarfing means also carried in conjunction with the mounting means in a position in the tubing beyond said weld point for engaging the interior of the tube along the welded seam to smooth out upset portions of the metal; and means mounted to apply pressure externally of the tube and reacting against pressure applied by said scarfing means.

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TUBE WELDING

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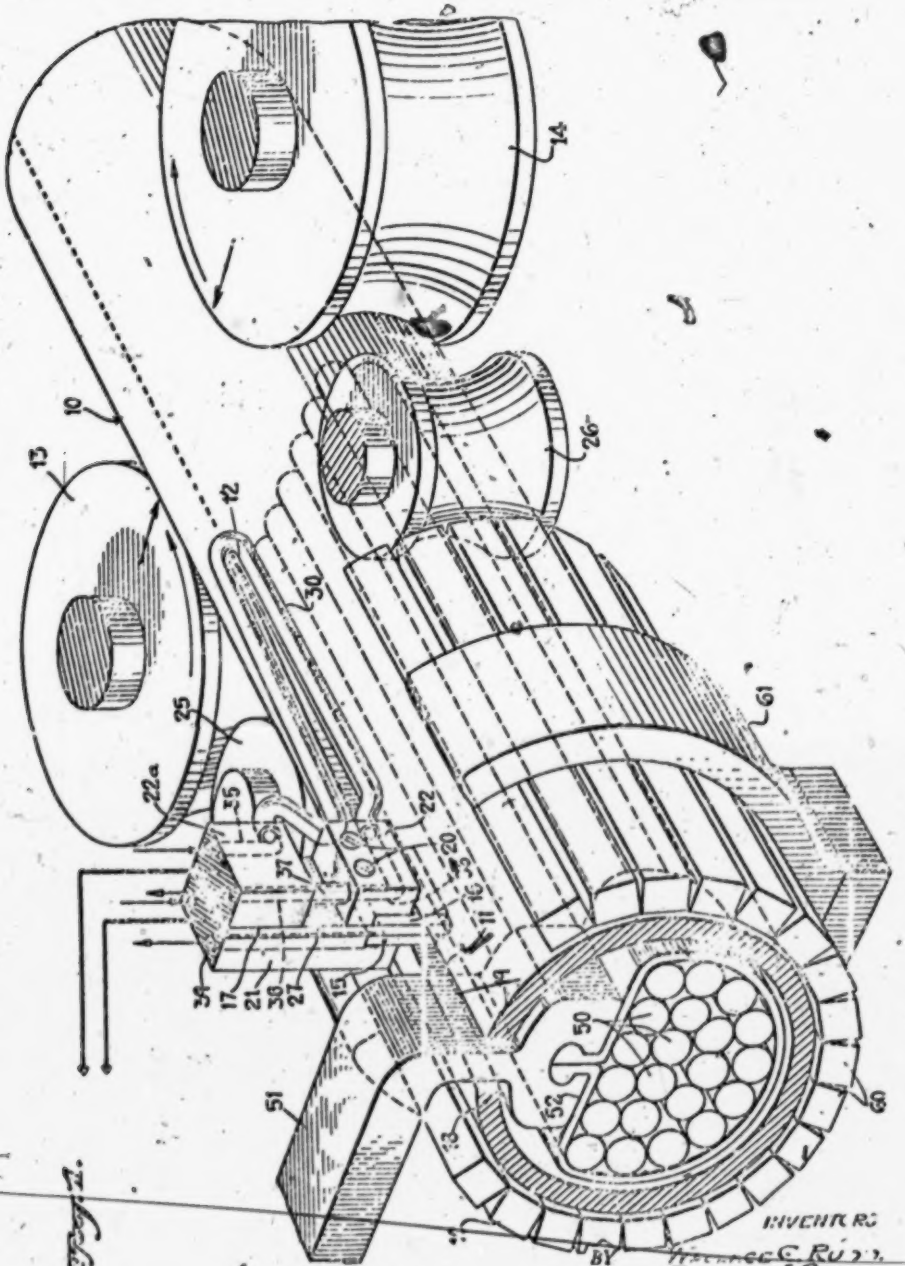

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Fig. 2.

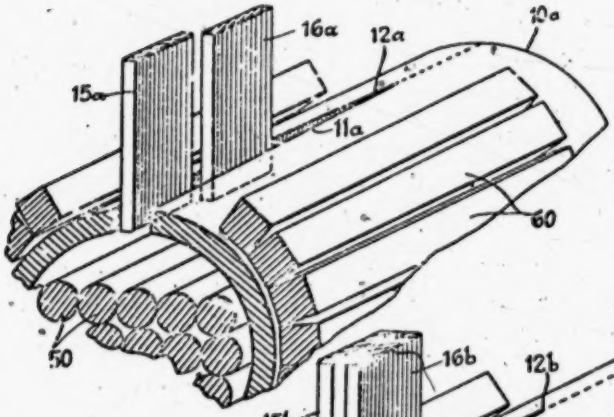


Fig. 3.

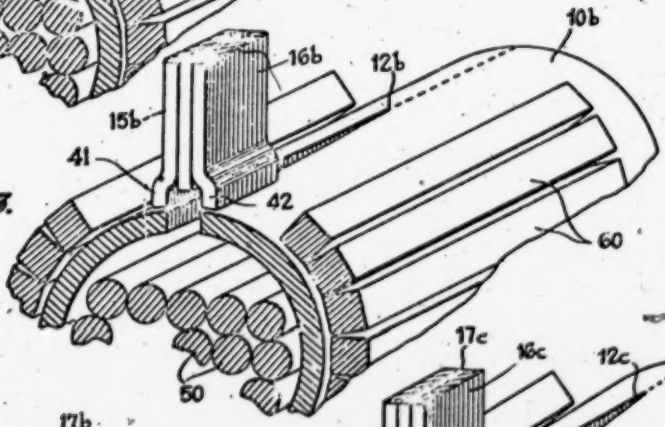


Fig. 5.

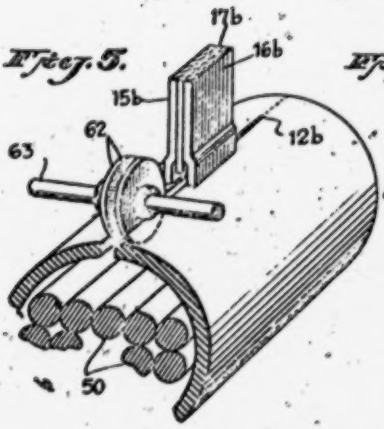
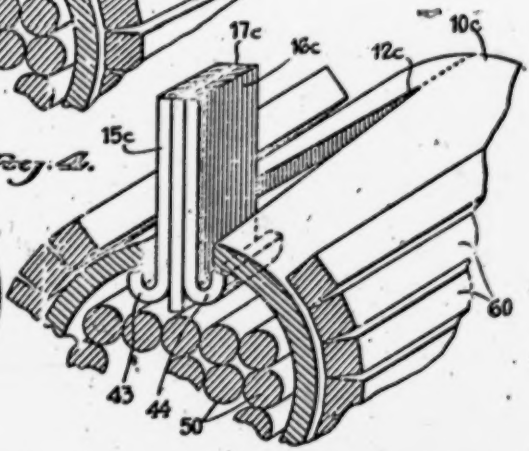


Fig. 4.



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TUBE WELDING

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10 Claims. (Cl. 219—59)

This invention relates to methods and apparatus for welding elongated metal portions together, such for example as the opposed edges along a seam in metal tubing.

More particularly, this invention in its presently preferred embodiment herein disclosed, relates to the general method of forming metal tubing which comprises continuously advancing an initially flat strip of the metal while shaping the same into a tube having a gap or slit along one side, such tube then being subjected to heating and pressure by rollers to close the gap and to weld together the gap edges. Heretofore it has been common practice in the manufacture of steel tubing by this general method to weld the gap edges by electrical resistance heating, that is, a heavy current is applied by the use of contacts in the form of copper rollers which press heavily against the metal of the tube at either side of the gap so that the current passes from one of these rollers to the other directly across the gap at the weld point and also circumferentially around through the metal of the tubing. Alternating current is generally used of a frequency from about 60 to 180 cycles, or sometimes up to 300 cycles in case the tubing is advanced rapidly and it is desired to avoid noticeable indications of the current pulsations in the resulting weld structure. Since with such methods it is essential that very heavy currents pass through the tube metal rapidly to heat the whole body of same, it is also necessary to apply the contact rollers to the tubing with heavy pressure to insure good electrical contact, and while steel tubing is in the usual cases capable of withstanding such pressure, yet if the tubing is of softer nonferrous metal such for example as aluminum, or has thin walls, sufficient pressure cannot readily be applied by the rollers to insure the required good contact with the tubing without danger of deforming the latter. Accordingly, in order to weld thin-walled tubing or tubing of such softer metals, efforts have been made to use induction heating as by encircling the advancing tube at a point shortly prior to the point of welding with an induction heating coil. However, by this method it is difficult to induce sufficient current to flow in the tubing to rapidly heat the same, particularly if the tubing is of non-magnetic metal, because of the fact that the workpiece constituting the tubing is an open-sided cylinder, and also because there must be an appreciable radial distance between the surrounding coil and the tubing in order to have sufficient mechanical clearance for moving the tubing at high speed. This method of inductively heating the tubing by surrounding the same with a coil, although successful under various circumstances, is inefficient in that a substantial degree of heating occurs throughout the walls of the tubing including the portions opposite from the gap.

With the present invention the difficulties of both of the above described methods may be avoided by means and methods which essentially involve resistance heating of the tube edges just prior to the welding of the same together, by the use of radio frequency current, preferably of a frequency of the order of hundreds of thousands of cycles, so applied that the greater part of the current flow in the tubing metal is along a V-shaped path formed by the two opposite edges of the tubing metal as they are about to come together at the point of welding. This is preferably accomplished by supplying the heavy current at high frequency to a pair of contacts which respectively engage the opposite sides of the tube metal just shortly prior to the point where the edges at the gap are brought together. Such contacts may slidably engage respectively the opposite edge surfaces in the gap, although in some cases it may be preferred to use either sliding or rolling contacts which engage the outer surfaces, or possibly the inner surfaces of the tube close to and on opposite sides of the gap. Sliding contacts engaging respectively the opposed edge surfaces within the gap may in some cases be preferable because such surfaces during the previous steps in the process of forming the tube will have become accurately trimmed and will ordinarily be in smooth bright condition so that a good electrical contact may be secured therewith, and the contacts also may act in effect as spreaders against which pressure rollers at opposite sides of the tubing act to press the gap edges toward each other in proper relation for uniform welding.

With heavy current of the above-mentioned high frequency range and relatively low voltage applied in this way, for reasons explained below, the use of simple sliding contacts is made possible without arcing troubles and by far the major part of the current flow in the tubing metal will be confined to a path running from one of the sliding contacts along the one edge at the gap to the point of welding and back along the opposite edge to the other contact, and very little of the current will flow around the circumference of the tubing. The reason for this is that such high frequency current tends strongly to follow the lowest impedance path offered, and since radio frequency impedance is mainly inductive reactance, one may examine the paths of current flow basically from an inductance point of view. And since the edges of the tube gap which are about to be welded are quite close together, the radio frequency current along these edges will have a much lower impedance path than any currents which tend to flow circumferentially around the tubing.

Since for the above reasons by far the greater part of the radio frequency current flow in the tubing will be confined along the approaching edge surfaces of the V-shaped gap, it will be apparent that after such edge surfaces have passed the contacts, the temperature thereof will still continue to increase and that such temperature will reach a maximum just as the edges merge at the weld point. Thus it follows that the gap edges of the tube may approach the contacts and pass the same before being raised to a very high temperature, and hence high temperature difficulties at the contacts are avoided. Yet since the radio frequency current continues to flow along the V-shaped gap edges until they merge at the weld point, such edges may be heated to a softened condition ready for welding, without being injured or distorted by coming into contact when in such condition with any part of the apparatus, and at no time do the edges need to be brought up to the desired welding temperature until just at the moment and at the localized area where they are about to merge together. Thus the heating current may be utilized with exceptionally high efficiency, because no part of the tubing, except at the weld point, has to be heated to high temperature, and even at that point the highest temperature heating may be confined as to time, to substantially the moment of welding. On the other hand, if direct current or low frequency methods are used as above referred to, then heavy pressure rolling contacts are required and the

current in following the lowest impedance path, will then largely follow lines of current flow in a plane or planes at the contacts and perpendicular to the axis of the tubing, and any minor part of the current which may tend to flow elsewhere, will be distributed through the mass of the metal of the tubing and hence not be effective for high temperature heating. Consequently the maximum temperature heating will be at or adjacent the contacts, rather than subsequently nearer the weld point.

In some cases, particularly if the tube diameter is relatively small, there will, however, be a tendency for at least a considerable part of the current to flow circumferentially around the tube instead of along the edges of the V-shaped gap and there may be a tendency for the weld point to vary its position along the direction of travel of the tube with consequent loss of efficiency and irregularities in the weld. We have discovered that these difficulties may be overcome in two ways by features which in fact supplement each other and make possible a surprising increase in the speed at which the tube may be advanced while still being welded with a high degree of uniformity. These features comprise first, the use of a conductor placed along above the edges to be heated and through which the radio frequency current is conducted in close proximity to the opposite edges and thereby substantially reducing the impedance of the radio frequency current path along such edges to and from the weld point. With the preferred construction above referred to, such conductor takes the form of a "hairpin" shaped portion placed along above the V-shaped gap. This hairpin conductor apparently so functions as to assist somewhat in maintaining the path of lowest inductance at a stabilized position, so that the weld point cannot move. Secondly, and more important, we have discovered that the impedance of the current path from one of the contacts circumferentially around the tubing to the other, may be greatly increased by mounting within the tubing and to some extent by mounting around just outside the tubing, magnetic core means of a suitable type, and the resulting increased impedance of this path causes the radio high frequency current still further to be concentrated where it is desired along the V-shaped gap edges. As a result, because of this second feature and with the use of a given amount of radio frequency current, the speed of the tubing may be increased 90 to 100% or more, using a given amount of power, while still making a uniform regular weld.

Various further and more specific objects, features and advantages of the invention will appear from the description given below taken in connection with the accompanying drawings illustrating by way of example certain preferred forms of the invention.

In the drawings:

Fig. 1 is a perspective view of the essential components of the apparatus of one embodiment of the invention and showing the position of a length of advancing tubing during the welding thereof; and

Figs. 2 to 5 inclusive are perspective views of alternative forms of contact arrangements which may be used in practicing the invention.

Referring now to Fig. 1 in further detail, a length of tubing is shown at 10 continuously advancing from suitable apparatus which has acted to form a flat strip of metal into a tube having a gap 11 the opposed edge surface portions of which are brought together and welded at point 12. The equipment for preliminarily forming such tubing with two true straight and bright opposing edge surfaces at the gap 11 does not form a part of the present invention and accordingly is not shown in the drawings. Such apparatus may be of the types heretofore commonly used for shaping such tubes.

The edges at the gap 11 are brought together at the point 12 as the tube advances by the action of opposed pressure rollers such as indicated at 13, 14, which also may be constructed and operated in the same manner as in various well-known tube-welding machines.

A pair of contacts 15, 16, separated by a layer of high heat-resistant insulation 17, are mounted on any suitable supporting structure in positions respectively to slidably engage the opposed tube edge surfaces 18, 19 in the gap 11. These contacts may be formed of suitable metal alloys capable of withstanding high temperatures without corrosion, and also capable effectively of resisting abrasion.

Contacts 15, 16 may be detachably connected as by screws as shown at 20, to conductor bars 21, 22, respectively formed of copper or other good electrical conducting metal. These conductor bars are connected to a source of radio frequency current such for example as the output terminals of a radio frequency transformer designed to transform current from a high voltage high frequency source to a low voltage radio frequency heavy current, preferably of a frequency of from about 300,000 to 500,000 cycles per second. A much higher frequency up to some millions may be used if desired, although in the usual case a frequency of about 400,000 cycles will be ample.

The amount of current which is caused to flow in the circuit of the contacts 15, 16 may vary within considerable limits depending upon the size and thickness of the tubing and its speed of longitudinal movement, and of course the rate at which it is necessary to apply heat will increase in proportion with any increase in speed of the advance of the tubing, and the amount of heating required will be substantially greater if the tube walls are thicker. Sufficient current should be applied so that the edge surfaces of the metal within the gap 11 just as they come in contact at point 12 will be fused to weldable condition while the tubing metal spaced from such edge surfaces still remains solid and firm. Generally speaking, tubes of larger diameters will require substantially no more heating current than smaller tubes of the same wall thickness. This together with the fact that application of the preferred high frequency current requires no heavy contact pressure, are important advantages of the invention, enabling its use on tubes of a wide variety of sizes, shapes, strengths and of different metals.

If desired, additional rollers as at 25, 26 may be applied to the sides of the tube in a position to firmly press the edges 18, 19 at the gap into contact with the contact members 15, 16, respectively. These rollers should preferably be of insulation material or have insulated surfaces for supporting shafts.

With the particular embodiment of the invention shown in Fig. 1, the conductor bar 20 is shown interrupted by a gap 27 and above which conductor bar portion 22a extends on to its current connection. The purpose of this gap is to provide for connecting in series with the circuit the hairpin-shaped conductor portion shown at 30 which extends from bar portion 22a down to a point close to one edge of the gap 11, thence along such edge to a point above point 12. At the latter point this conductor portion is bent around to return along close to and just above the other edge of the gap 11 and thence into contact with conductor bar portion 22. The purpose of the conductor portion 30 in the position shown is as above explained to aid in concentrating the flow of current along the edges of the gap 11, by reason of what is sometimes referred to as the "proximity effect" in the induction heating art. That is, the use of the loop 30 acts to cause a current path through the weld point of a somewhat lower inductance than otherwise would occur, because of the proximity of the current carried in this loop.

It will be understood that with the particular construction shown in Fig. 1 the current flows from the source through the conductor bar portion 22a, thence through the hairpin-shaped conductor 30 into conductor bar portion 22 to contact 16, thence along one edge surface of

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the gap 11 to the region of the point 12 and back along the other edge surface in the gap to contact 15 and back to the current source through conductor bar 21.

In view of the heavy current used, it will ordinarily be necessary or desirable to provide cooling means for the conductor bars 21, 22, 22*a*. This may be accomplished by forming these members with cavities as shown through which cooling fluid may be circulated. For example, in member 22*a* the fluid may be conducted through a cavity 35, thence through the hollow interior of conductor 30 to cavity 36 in conductor bar 22, thence through a tube of insulation material 37 into a cavity 38 in conductor bar 22*a*. The conductor bar 21 may be formed with a U-shaped cavity 39 for receiving the cooling fluid.

It will be understood that suitable insulation supporting and mounting means (not shown) may be provided for the conductor bars to rigidly retain the same in the positions shown or so as to be adjustable with respect to the weld point 12.

As shown in Fig. 2, the contacts as at 15*a* and 16*a* for applying the high frequency to the facing edges and the gap need not necessarily be in directly opposed relation, but may be offset one in advance of the other. This arrangement may be particularly desirable where it is possible to have a relatively short path of current flow from the contacts to and from the weld point and with a consequent possibility of having a narrower gap in the tube where the gap edges are to be heated, thus reducing the reactance of the current path.

In other cases, as shown in Fig. 3, if preferred the contacts as at 15*b*, 16*b* may be shaped at their lower ends as shown at 41, 42 so as to contact with the outer surface of the tube 10*b* along lines close to the gap edges. With this arrangement the gap may be made still narrower at the points of contact, thereby further minimizing the impedance of the path of current flow from the contacts, to and from the weld point. Further, as shown in Fig. 4, if desired the contacts as at 15*c*, 16*c* may be so arranged as to extend down through the gap and be provided with tip portions 43, 44 for engaging the interior surface of the tube at points along and close to the gap. This form may be preferred where the interior surfaces of the tube are so formed as to be uniform and bright for good contact, or where it is desired to insure adequate heating along the lower part of the gap edges when of relatively thick metal.

The construction shown in Fig. 5 may be the same as that of Fig. 3 except that here the contacts 15*b*, 16*b* are if desired brought closer to the weld point 12*b* and means as at 62 is provided within the tube gap in advance of the contacts for preventing the edges of the gap from prematurely or irregularly coming together. In cases where the contacts are not interposed between the gap edges, there may be some tendency for the gap edges to approach each other too soon after leaving the contacts and with only a slight angle therebetween, the angle being so slight that the weld point may tend to fluctuate back and forth somewhat longitudinally of the tube, thereby giving an irregular weld. This difficulty may be avoided by interposing the spacing or spreader means 62 just in advance of the contacts. The means 62 may comprise a pair of thin metal rotatable discs for example insulated from each other and from the shaft 63 carrying same. A suitable supporting structure (not shown) with bearings and which may be adjustable in position is of course provided for the shaft. Such a means may also be used in connection with the arrangements of each of the other figures.

It will be understood that with all of the forms of contacts as shown in Figs. 2–5 inclusive, suitable supporting structure and fluid cooling means may be provided similarly as in Fig. 1 and also, if desired, hairpin-like conductor portions such as shown at 30 in Fig. 1 may be used with the contacts of Figs. 2–5.

Reverting now to Fig. 1, the magnetic core means above referred to will now be described in further detail. Such means may, for example, comprise a plurality of rods as at 50 of magnetic material retained, tied or supported in any suitable way within the advancing tube, for example by means such as an insulation bracket 51 extending down through the gap 11 and of suitable shape to grip or secure in place an insulation band or the like as at 52 for embracing the rods 50. Such rods may for example be formed of sintered magnetic oxide, an insulation material, preferably of types now well known, which have a low loss factor and high volume resistivity, for example such as the material marketed under the name Ferramic by General Ceramic & Steatite Corp. However, this core means may be of other forms of material which will have a permeability (mu) greater than one, preferably substantially greater, and such that eddy current losses therein will be minimized. As shown, this magnetic core means preferably extends from a position beneath the contacts within the tube and to a region beneath or nearly beneath the weld point 12. As here shown, the magnetic core means substantially fills the space within the tube except for the region just beneath the gap 11 and the necessary clearance space along the tube walls, but in some cases it may be necessary only to provide such core means in a form which will have an arcuate cross-section and be positioned around close to the interior surfaces of the tube.

Such internal magnetic core means may be supplemented by rods or strips of like or similar magnetic material located around the outside surface of the tube in the form for example of rods as indicated at 60, held in place for instance as by an insulation bracket 61 suitably secured thereto. But generally the internal core means will be found to be much more effective than the external means.

With the internal Ferramic core means such as above referred to, it has been found possible to increase the inductance of the circumferential path from one contact 15 to the other contact 16 by as much as 8 to 10 times and with such core material having low resistivity, the losses of power are not appreciably increased beyond what will occur in the absence of such core means. As a consequence, the current flowing from the electrodes to and from the weld point along the V-gap edges will be increased enough so that, for example as found by one typical test, an aluminum tube 2" in diameter and 81 mils in thickness, could be welded at the rate of 45 feet per minute, using current of a frequency of 400 kilocycles from a 20 kw. generator, whereas without the core means but under conditions otherwise the same, the tubing could be advanced and properly welded only at rates up to about 24 feet per minute. In the above described test the parts were so arranged that the distance between the weld point and the trailing edges of the contacts was about ¾". It has been found that this distance is preferably somewhat less in welding non-ferrous tubing. In a similar test in welding steel tubing, such distance was preferably about 2¼". In a typical test with steel tubing, using a current of a frequency of 375 kilocycles from a 20 kw. generator, it was found that the tubing could be welded at a speed of over 50 feet per minute the tubing being 2" in diameter and its walls being of a thickness of 0.052". There was no objectionable upset ridge or other irregularity formed along the line of the weld. Of course, with more powerful radio frequency generators, the above noted welding speeds may be greatly increased. One of the important advantages of the invention is that the larger radio frequency generators for high speed welding are very much less expensive than low frequency generators having the necessary power and heretofore used for tube welding. A further advantage is that with the contact arrangements here shown, the machine can be set up and adjusted for different sizes

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of tubing within a few minutes as contrasted with many hours required with prior apparatus.

It should be noted that the magnetic core means as used in the combination here described, performs a quite different function from that of magnetic core means as sometimes heretofore used in connection with the induction heating of tubing and where an induction heating coil is positioned around the tube. In that case, the addition of the core increases the total magnetic flux produced by the coil, which in turn increases the total current circulating circumferentially in the tube by reason of induction as distinguished from the resistance heating method of the present invention. In the present case, the situation with a magnetic core is in fact quite the opposite of that with such induction heating methods, because with the latter the effect is greatly to increase the current flow around within the tubing areas opposite from the gap, whereas with the present invention, the core greatly reduces the current in the tubing in directions around the tubing and compels the great majority of the current to follow the useful path from the contacts to and from the weld point.

In addition to the above-indicated advantages of the method of this invention when radio frequency current is used, there are various other important benefits arising from the following facts. The amount of radio frequency power required is a function of the thickness of the metal of the tube and largely independent of the tube diameter. Thus substantially no more power is required for welding large tubes as compared with small diameter tubes, this result occurring by reason of the fact that the heating is confined to the very edges which are to be welded. This is contrary to induction methods, where the larger the diameter of the tube, the greater the power supply must be, because in any event with induction methods, a considerable part of the heating effect is distributed in regions away from the gap edge surfaces. Substantially less power is required by our preferred methods than with induction methods, regardless of the diameter of the tubing being welded, because with induction methods, there is no way in which the maximum heating may be concentrated at the weld point, whereas by the method of this invention, that is the only point which needs to be brought up to actual welding temperature.

The preferred methods of this invention have the further advantage in that only a single pair of contacts is needed and yet the heating effect accomplished therewith is fully effective all along the edges of the V-shaped gap from the contacts clear to the weld point where the temperature becomes the maximum. On the other hand, with low frequency methods, if heavy currents are to be applied across the gap, either heavy rollers of high conductivity applying great pressure have to be used, or a plurality of pairs of such rollers, each of which can only cause momentary heating with a chance for the tube even to cool following each pair and with no chance for a sustained and increased heating of the gap edges after they have left the contacts.

The greatest advantages of the present preferred methods occur both with ferrous and non-ferrous relatively thin-walled tubing of types which cannot withstand the heavy contact pressures required to apply the strong heating current necessary for the prior resistance heating methods, especially if the tubing is to be advanced at high speed for economical production.

Once having set up the apparatus to make tubing of given dimensions and with contacts at the gap edges located a given distance from the weld point, one may determine a suitable frequency which will cause the current to follow the desired path according to the invention, by mathematical computations, or a suitable frequency may readily be determined by brief tests. Frequencies in the neighborhood of 100,000 cycles, are suitable so far as the invention is concerned, although same may involve at present some practical difficulties in that this range falls between the higher frequency range of motor-driven generators and the lower ranges economically most practical for vacuum tube radio frequency generators. Accordingly, as indicated above, frequencies of the order of hundreds of thousands of cycles or higher are at present preferable in practice. Same may be easily and economically achieved with vacuum tube generators.

This application is a continuation in part of our copending application Serial No. 332,422, filed January 21, 1953, and which discloses apparatus the same as disclosed in Figs. 1–4 herein, except without the magnetic core material within and about the tubing.

Although certain particular embodiments of the invention are herein disclosed for purposes of explanation, various further modifications thereof, after study of this specification, will be apparent to those skilled in the art to which the invention pertains. Reference should accordingly be had to the appended claims in determining the scope of the invention.

What is claimed and desired to be secured by Letters Patents is:

1. Method for welding together the edges of a longitudinal gap in metal tubing which comprises longitudinally advancing the tubing while subjecting the same to pressure from opposite sides thereof to bring the gap edges together at a welding point as a narrow V-shaped formation, and while heating said edges to welding temperature by applying contacts connected to means providing a source of high frequency current, to points on the tubing at opposite sides of the gap at a position shortly in advance of said point, said current being of a sufficient frequency whereby the greater part of the current flowing in the tubing metal from one contact to the other will follow a path from one of said contacts along close to one edge of the gap to said welding point and back along close to the opposite edge of the gap to the other contact, and also conducting such current along and just above said V formation, to decrease the reactance of said path.

2. Apparatus for welding together the edges of a longitudinal gap in metal tubing, which comprises means for longitudinally advancing the tubing while subjecting the same to pressure at opposite sides of the gap to bring such edges together at a welding point in a narrow V-shaped formation, a pair of contacts mounted respectively to be slidably engaged by surfaces of the metal of the tubing along opposite sides of the gap at a position shortly in advance of said point, means for connecting a source of high frequency current to said contacts, and a conductor member of a generally corresponding V-shape mounted along just above the position of said gap in advance of said point, said conductor member being connected in series with the connection from said source to one of said contacts.

3. Apparatus for welding together the edges of a longitudinal gap in metal tubing, which comprises means for longitudinally advancing the tubing while subjecting the same to pressure at opposite sides of the gap to bring such edges together at a welding point in a narrow V-shaped formation, a pair of contacts mounted respectively to be slidably engaged by the opposite edge surfaces of the metal of the tubing within the gap at a position shortly in advance of said point, a source of high frequency current connected to said contacts, and a conductor member of a generally corresponding V-shape mounted along just above the position of said gap in advance of said point, said conductor member being connected in series with the connection from said source to one of said contacts.

4. Apparatus for welding together the edges of a longitudinal gap in metal tubing, which comprises means for longitudinally advancing the tubing while subjecting the same to pressure at opposite sides of the gap to bring such edges together at a welding point in a narrow V-

shaped formation, a pair of contacts mounted respectively to be engaged by surface of the metal of the tubing at opposite sides of the gap at a position shortly in advance of said point, means for connecting a source of high frequency current to said contacts, and a conductor member of a generally corresponding V-shape mounted along just above the position of said gap in advance of said point, said conductor member being connected in series with the connection from said source to one of said contacts.

5. Apparatus for welding together the edges of a longitudinal gap in metal tubing comprising in combination: means for longitudinally advancing the tubing while subjecting same to pressure at opposite sides of the gap to bring such edges together at a welding point in a narrow V-shaped formation; a pair of contacts mounted respectively to be engaged by surfaces of the metal of the tubing at or adjacent opposite sides of the gap and at a position shortly in advance of said point; a source of electrical current of a frequency of the order of 100,000 cycles per second or higher and having its terminals respectively connected to said contacts whereby such current will follow a path from one of said contacts along one edge of the gap to said welding point and back along on the opposite edge of the gap to the other contact, core means; and means for mounting same inside the tubing adjacent tubing surface areas at the region of other paths of current flow from said contacts circumferentially of the tubing, for increasing the reactance of such other current paths and thereby to increase the current flow along the edge surfaces of said gap, such core means comprising a magnetic but substantially an insulating body having a low loss factor, high volume resistivity and magnetic permeability substantially greater than unity.

6. Apparatus for welding together the edges of a longitudinal gap in metal tubing comprising in combination: means for longitudinally advancing the tubing while subjecting same to pressure at opposite sides of the gap to bring such edges together at a welding point in a narrow V-shaped formation; a pair of contacts mounted respectively to be engaged by surfaces of the metal of the tubing at or adjacent opposite sides of the gap and at a position shortly in advance of said point; a source of electrical current of a frequency of the order of 100,000 cycles per second or higher and having its terminals respectively connected to said contacts whereby such current will follow a path from one of said contacts along one edge of the gap to said welding point and back along on the opposite edge of the gap to the other contact; and core means and means for mounting same inside the tubing adjacent tubing surface areas at the region of other paths of current flow from said contacts circumferentially of the tubing, for increasing the reactance of such other current paths and thereby to increase the current flow along the edge surfaces of said V-shaped gap, such core means comprising a sintered magnetic oxide insulating material having a low loss factor and high volume resistivity and magnetic permeability substantially greater than unity.

7. Method for welding a seam extending along opposed edges of two elongated metal portions, which comprises: rapidly advancing said portions with their said edges passing along the line of the desired seam and past a weld point; firmly retaining said edges together as they reach the region of said weld point; maintaining on said edges over a distance substantially in advance of said weld point flows of electrical current of a frequency of the order of 100,000 cycles per second or higher for progressively heating such edges up to welding temperature upon reaching said point; and increasing the reactance of current paths in the metal spaced from the line of the desired seam by maintaining adjacent such current paths a body or bodies of magnetic but substantially insulating material having a low loss factor, high volume resistivity and magnetic permeability substantially greater than unity, whereby the resulting increased reactance of said paths increases the current flow along on said edges.

8. Apparatus for welding a seam along opposed edges of two elongated metal portions which comprises: means for rapidly advancing said portions with their edges passing along the line of the desired seam and past the weld point; a source of electrical heating current of a high frequency of the order of 100,000 cycles per second or higher; a pair of contacts positioned respectively to be engaged by said edges at or adjacent the line of the desired seam shortly in advance of said point; and connections for connecting the terminals of said source respectively to said contacts, whereby such current will follow a path from one of said contacts along on one of said edges to the weld point and back along the other edge to the other contact, and one of said connections including a generally hairpin-shaped portion which extends from one of said contacts along just above the position of said line to the weld point and back to a location close to the other contact, thereby to reduce the reactance of the paths of said current on said edges and thus acting to cause concentration of the current along on said edges.

9. Apparatus for welding a seam along opposed edges of two elongated metal portions which comprises: means for rapidly advancing said portions with their edges passing along the line of the desired seam and past the weld point; a source of electrical heating current of a high frequency of the order of 100,000 cycles per second or higher; and contact means for applying said current to flow along said edges for a substantial distance in advance of the weld point for progressively heating such edges up to welding temperature upon reaching said point, fluid-cooled connections being provided between the terminals of said source and said contacts respectively, one of said connections including portions which extend along in closely spaced relation to the paths of said current flowing on said edges, such connection portions acting to decrease the reactance of said current paths and thereby acting to cause concentration of the current along on said edges.

10. Apparatus for welding together the edges of a longitudinal gap in metal tubing comprising in combination: means for longitudinally advancing the tubing while subjecting same to pressure at opposite sides of the gap to bring such edges together at a welding point in a narrow V-shaped formation; a pair of contacts positioned respectively to be slidably engaged by surfaces of the metal of the tubing at or adjacent opposite sides of the gap and at a position shortly in advance of said point said contacts being formed of abrasion and high temperature resistant metal; a pair of metal supports for said contacts respectively insulated from each other and formed with fluid-cooling cavities located in positions for close heat transfer relationship to said contacts; a source of electrical current of a frequency of the order of 100,000 cycles per second or higher, and connections from said source to said supports respectively whereby such current will follow a path from one of said contacts along on one edge surface of the gap to said welding point and back along on the opposite edge surface of the gap to the other contact.

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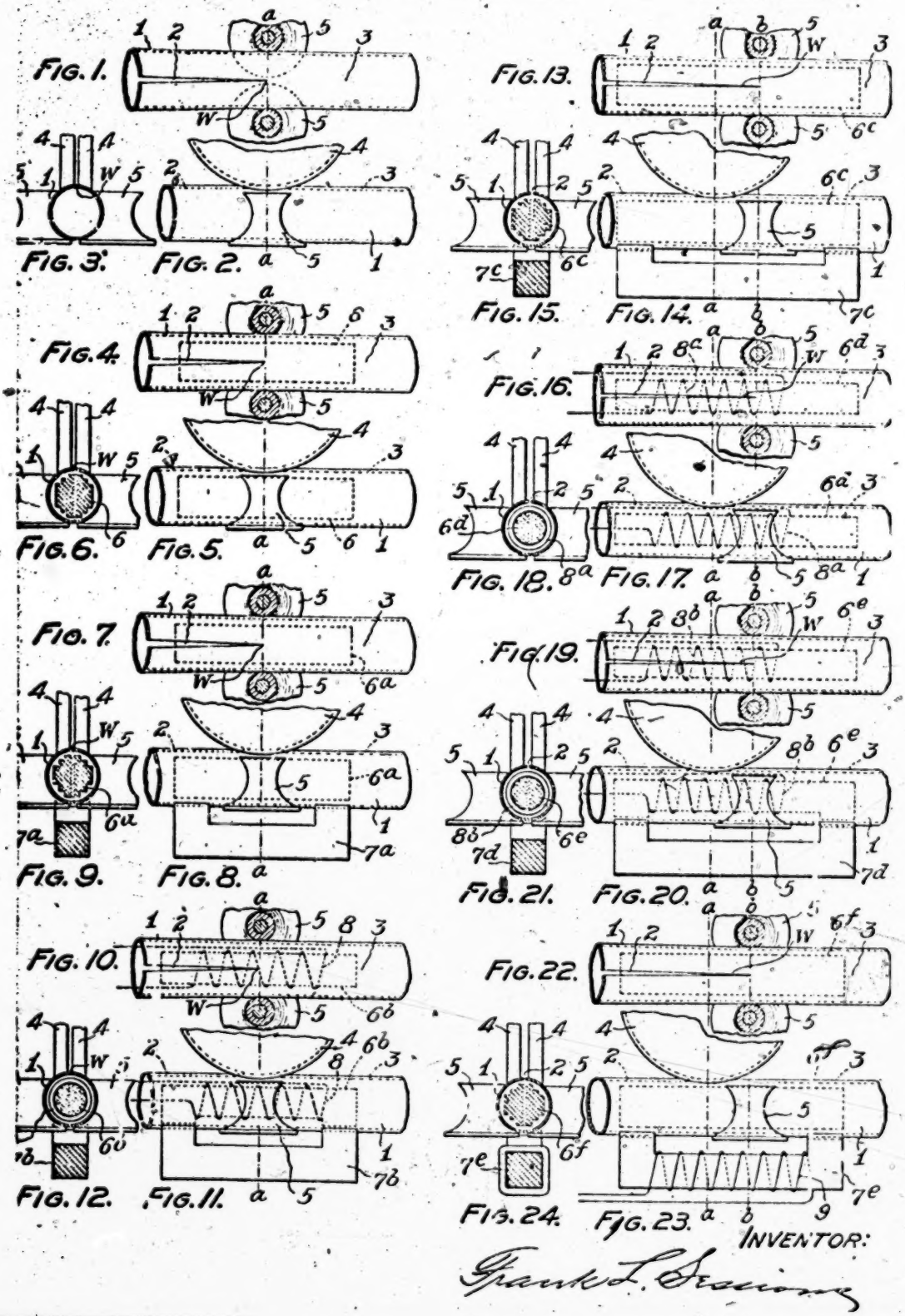
Defendants' Exhibit DX-C-Tab 4

Dec. 6, 1938. F. L. SESSIONS 2,139,211

METHOD OF AND APPARATUS FOR WELDING TUBING

Filed June 21, 1934 4 Sheets-Sheet 1



INVENTOR:

Frank L. Sessions

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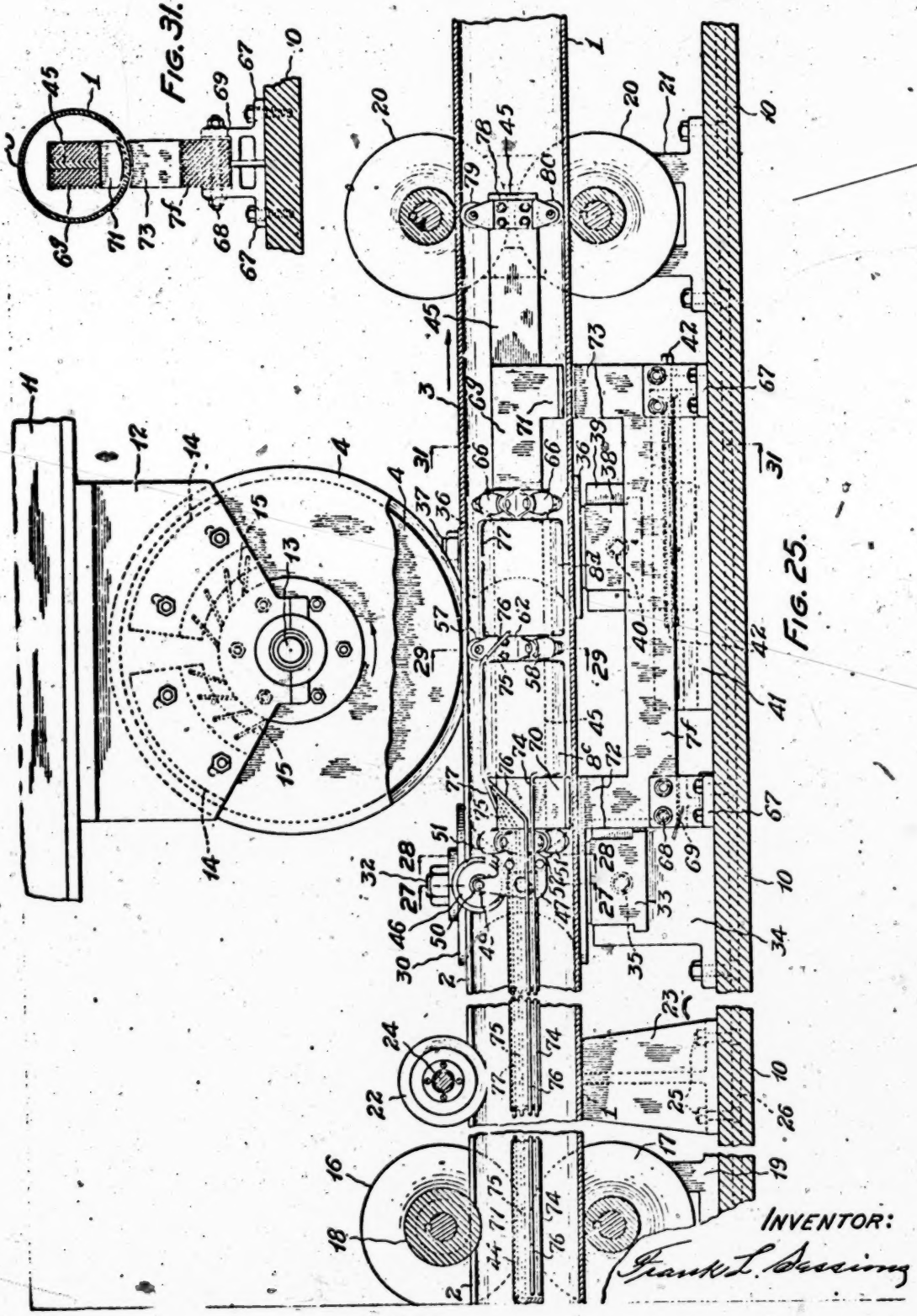
Dec. 6, 1938. F. L. SESSIONS 2,139,211

METHOD OF AND APPARATUS FOR WELDING TUBING

Filed June 21, 1934 4 Sheets-Sheet 2

FIG. 31.

FIG. 25.



INVENTOR:
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Dec. 6, 1938. F. L. SESSIONS 2,139,211

METHOD OF AND APPARATUS FOR WELDING TUBING

Filed June 21, 1934 4 Sheets-Sheet 3

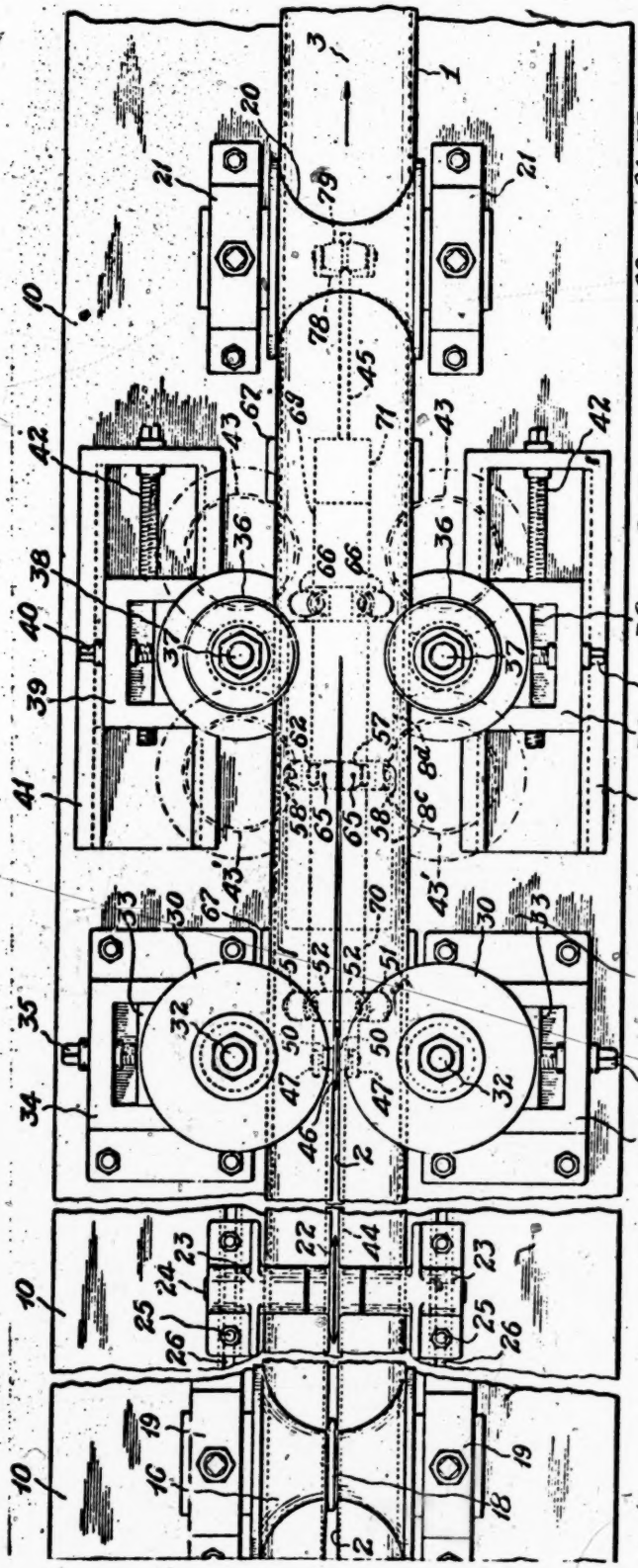

FIG. 26.

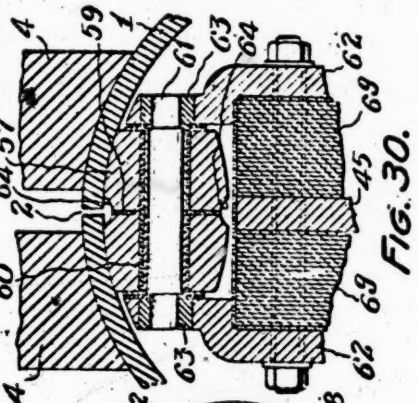

FIG. 30.

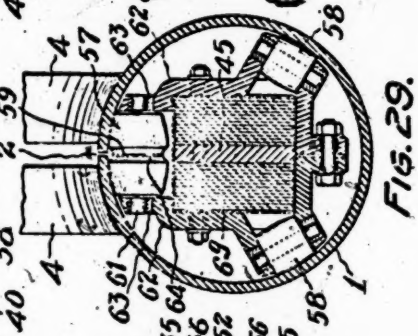

FIG. 29.

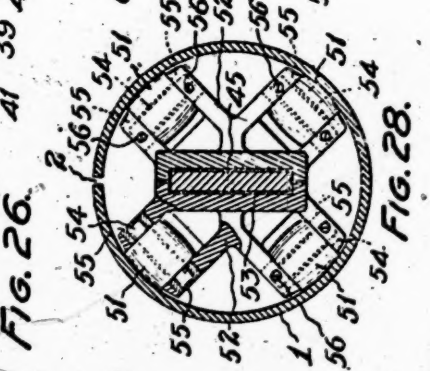

FIG. 28.

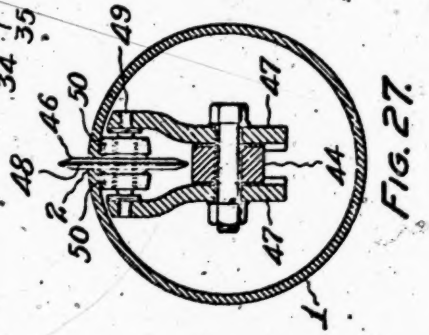

FIG. 27.

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METHOD OF AND APPARATUS FOR WELDING TUBING

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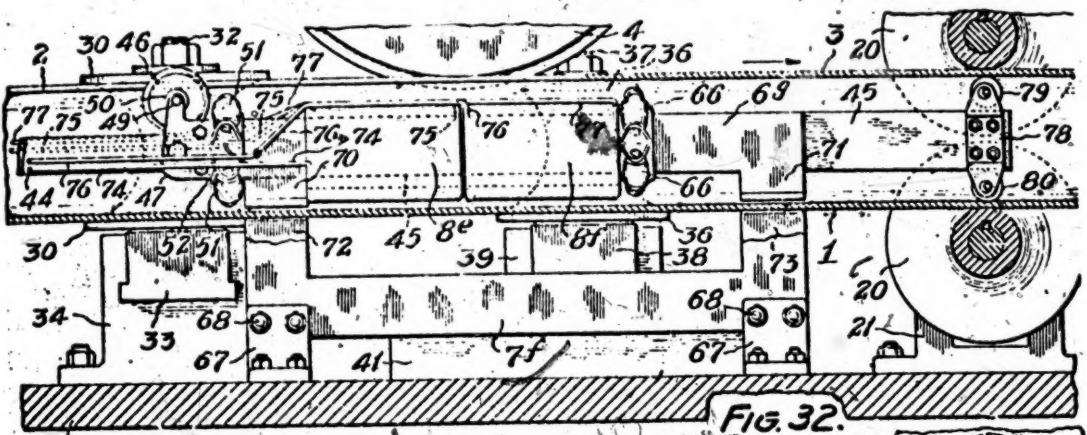

FIG. 32.

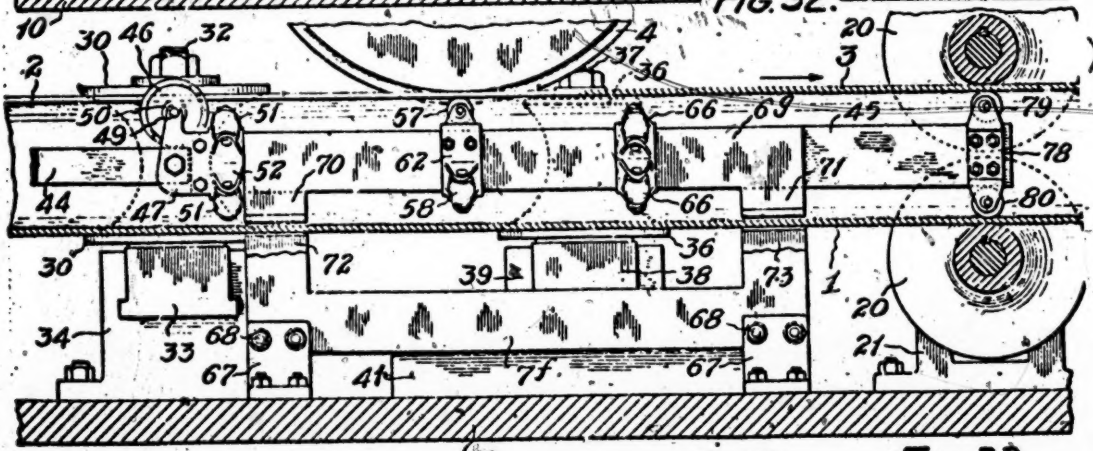

FIG. 33.

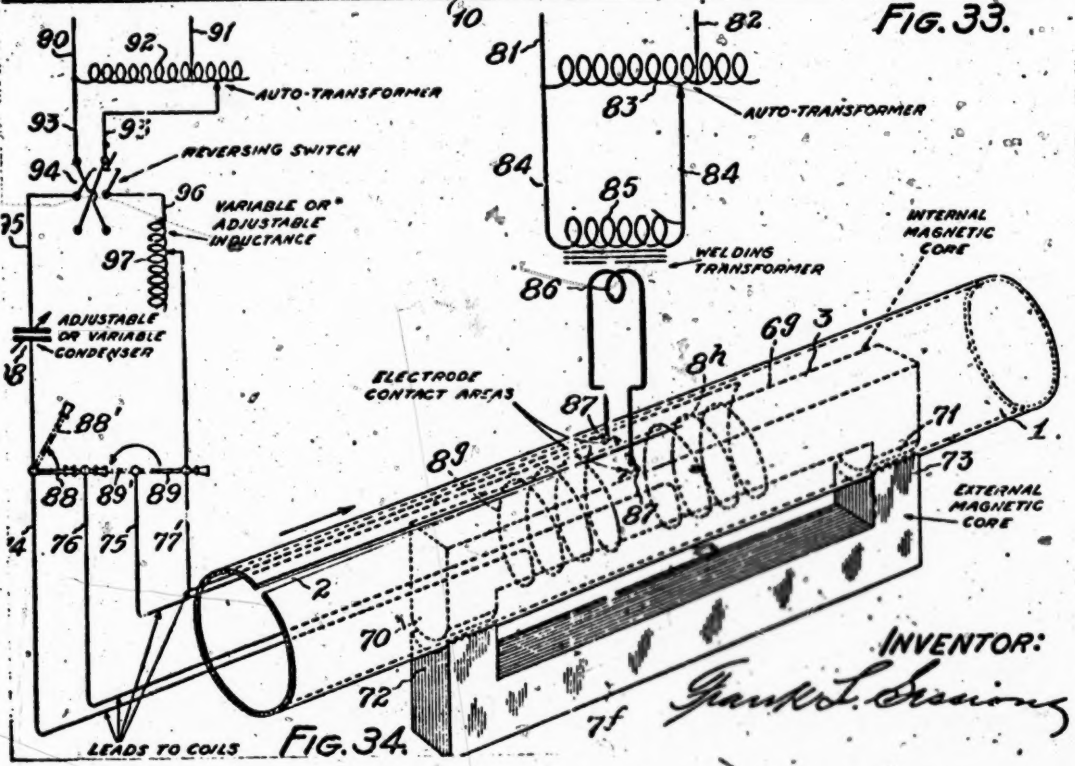

FIG. 34.

INVENTOR:

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Defendants' Exhibit DX-C-Tab 4

Patented Dec. 6, 1938

2,139,211

UNITED STATES PATENT OFFICE

2,139,211

METHOD OF AND APPARATUS FOR WELDING TUBING

Frank L. Sessions, Lakewood, Ohio

Application June 21, 1934, Serial No. 731,791

22 Claims. (Cl. 219—10)

My invention relates to a method of and apparatus for welding a longitudinal seam in tubing by the electric resistance method and specifically to electric resistance welding wherein the electric current which is effective in flowing across the seam edges to heat the metal is applied to the tubing by the contact therewith of electrodes or other suitable, current-conducting, or contact members. This form of welding may be termed "contact" electric resistance welding, as distinguished from "induction" electric resistance welding. My invention is particularly adapted to the progressive welding of tubular articles and specifically to the butt welding of longitudinal seams in metal tubes or pipes, although it will be apparent to those skilled in the art that certain features of my invention may be advantageously applied to stationary electric resistance welding of longitudinal seams in tubular articles. It will be apparent that my invention is particularly adapted to the method of electric resistance welding known as "flash" welding.

In the progressive electric resistance welding of longitudinal seams in tubular articles it is common practice to move the article longitudinally of itself at a constant speed so that cold unheated portions of the seam edges are successively and continuously heated and pressed together in a heating and welding zone to complete a weld between abutting edges of the seam. Electric resistance welding may be either "upset butt" welding or "flash" welding. In either case the heat necessary to make the weld is developed by a flow of electric current of very large amperage across the seam cleft from one seam edge to the other. In one type of machine used today the welding current is conducted to the tubing to be welded by copper contacts or electrodes which roll on the surface of the tubing on each side of the seam, as shown in Patent No. 1,388,434 to Johnston and in my Patent No. 1,722,711. This is "contact" resistance welding. Another type of resistance welding which is practiced today in the progressive welding of tubular articles utilizes the tube itself as a single turn secondary of a transformer with a suitably disposed and energized induction coil as the primary of the transformer. The welding current is caused to flow in the tube and across the seam as a result of electromotive force induced directly in the tube. This is "induction" electric resistance welding and the principles involved are described in my Patents 1,365,198 and 1,365,199 of January 11, 1921.

In contact welding, as heretofore practiced, the current flows across the seam in a very narrow zone. In induction welding the heating current flows across the seam in a zone of considerable length compared to contact welding and the weld is commonly a flash weld or a combined flash and upset butt weld. In induction welding slight irregularities on the surfaces of the seam edges are burned and flashed away and therefore the edge surfaces and the over-all width of the strip or plate which is formed into the tubular shape, need not be so carefully and accurately finished to size as is the case with contact welding.

When practicing progressive, contact welding the heating current is usually conducted to the article by roller electrodes, and two parallel paths for the electric current exist in the metal of the tubular article. One of these paths is between the electrodes and across the seam, and the other of the paths is around the body of the tubular article opposite the seam. This latter path is commonly described as being the path around the back of the tube or pipe. The magnitude of the current which flows around the back of the tube or pipe varies with the diameter, the wall thickness, the material being welded, the resistance of the path across the seam, and the voltage applied to the tube at the electrodes. If the resistance of the path across the seam is high, a larger proportion of the total current conducted to the pipe by the electrodes will flow around the back of the pipe. It will be obvious that when the resistance of the path across the seam is increased, it becomes necessary to increase the voltage applied to the pipe at the electrodes in order to cause a current of sufficient magnitude to flow across the seam, and this higher voltage increases the magnitude of the current flowing around the back of the pipe. For this reason in practicing contact welding it is necessary that the electrodes contact with the surface of the pipe closely adjacent to the seam on each side of the seam and that the path through the tube and across the seam be as short as possible and not be extended longitudinally or axially of the pipe. This latter result has been unavoidable in the heretofore practiced methods of contact welding of tubing and is accomplished by positioning the pressure rolls, which, together with the electrodes, form the welding throat, substantially in the same vertical, transverse plane with the centers of the electrodes.

My invention makes possible contact, electric-resistance welding wherein the current conducted from the electrodes to the pipe or other tubular

article being welded is caused to flow longitudinally as well as transversely of the pipe in passing between the electrodes and across the seam, so that the length of the seam across which the current is flowing at any one instant may be considerably increased over the short length of seam across which the current which is effective in heating the edges prior to the completion of the weld, flows in contact welding as heretofore practiced. This makes possible the utilization of the flash method of electric resistance welding, or a combined flash and upset butt method of electric resistance welding, with the resultant advantages which are present in induction welding, such as the burning and flashing away of irregularities on the edges of the seam and the avoidance of holes or unwelded spots due to surface irregularities and imperfections on the edge surfaces of the seam or on the surface where the electrodes contact. My invention has an advantage over induction welding in that the welding zone need not be so extended as is the case with induction welding, and the welding is completed nearer to the ends of the tubular article, particularly the trailing end.

This application is a continuation in part of my co-pending application, Serial No. 555,820, filed August 7, 1931 (now Patent No. 2,086,305, granted July 6, 1937).

Among the objects of my invention are:

The provision of method and apparatus for electric resistance welding of tubing wherein the heating and welding current which is conducted to the tube by the contact therewith of electrodes, is caused to flow across the seam and the tendency for a part of the current to flow around the back of the tube is greatly minimized, or entirely overcome.

The provision of method and means for applying a suitable electric resistance welding voltage to a tube by contact and inducing within the wall of the tube an electromotive force suitable to oppose the applied voltage and greatly reduce, or prevent, any flow of current from the electrodes around the back of the tube.

The provision of a method and apparatus for the progressive flash welding of a longitudinal seam in tubular articles wherein the heating and welding current is conducted to the tube by the contact therewith of roller electrodes, or other suitable current conducting contact members.

The provision of a method and means suitable for causing a heating and welding current conducted to a tube from an external source by current-conducting contact members to flow across the seam in a zone of appreciable longitudinal extent.

The provision of a method and means for progressive contact electric resistance flash welding wherein the heating current flows across the seam in a flash heating zone of appreciable longitudinal extent.

The provision of a magnetic core of low magnetic reluctance inside of a tube and a magnetic core of low magnetic reluctance outside of the tube, the outside core forming a return magnetic circuit for the magnetic field developed in the inside core, the outside core being spaced from the inside core at its ends by only short air gaps so that a substantially closed magnetic circuit is formed.

The provision of an energized coil adapted to develop a magnetic field inside of a tube being welded, the magnetic field extending generally parallel to the axis of the tube from a point considerably in advance of the contact with the tube of current-conducting electrodes to a point considerably beyond the contact of the electrodes.

The provision of a method and means for progressive, contact, flash electric resistance welding of a longitudinal seam in a tube wherein the seam edges are maintained in spaced-apart relation between electrodes which conduct the heating and welding current to the tube.

The provision of means for maintaining the seam edges of the tube to be welded in spaced-apart relation while passing the zone of electrode contact with the tube.

The provision of supporting means inside of a tube capable of withstanding electrode contact pressure on the outside of the tube, while the edges of the seam are maintained in spaced-apart relation between the electrodes.

The provision of an electric coil suitably positioned with respect to the tube being welded to develop an electromotive force in the wall of the tube, and means for controlling the phase relation and the magnitude of the voltage developed in the wall of the tube with respect to a voltage applied or conducted to the tube by electrical contact, so that the voltage induced in the wall of the tube is substantially opposed to the voltage applied to the tube.

The provision of an electric coil for developing a magnetic field which extends in an axial direction inside of a tube at and on each side of the point of contact with the tube of current conducting electrodes, and means for adjusting or varying the reactance of the circuit supplying power to the electric coil, and means for varying the voltage impressed on the circuit supplying power to the electric coil.

The provision of a method and means for the progressive flash welding of a longitudinal seam in a tube by the contact method whereby the location and length of the zone of flash-heating current flow across the seam edges may be readily located, controlled and regulated.

These and other objects which will be apparent from the specification and drawings are accomplished by the use of my invention.

In the drawings:

Figs. 1, 2 and 3 are diagrammatic, plan, side elevation, and vertical cross section, respectively, showing the conventional arrangement for progressive electric resistance welding of a tubular article by the contact method as it has been heretofore practiced. The vertical cross section, Fig. 3, is a section taken in a plane indicated by the line a—a on Figs. 1 and 2.

Figs. 4, 5 and 6 are diagrammatic, plan, side elevation, and vertical cross section on the line a—a of Figs. 4 and 5, respectively, illustrating the use of an internal magnetic core.

Figs. 7, 8 and 9 are diagrammatic, plan, side elevation, and vertical cross section on the line a—a of Figs. 7 and 8, respectively, illustrating the use of an internal magnetic core and with the addition of an external magnetic core which forms a return magnetic circuit for the magnetic lines of force developed inside of the tube.

Figs. 10, 11 and 12 are diagrammatic, plan, side elevation, and vertical cross section on the line a—a of Figs. 10 and 11, respectively, illustrating the use of apparatus having a coil on an internal magnetic core.

Figs. 13, 14 and 15 are diagrammatic, plan, side elevation, and vertical cross section on the line a—a of Figs. 13 and 14, respectively, showing one form of my invention wherein the weld-

ing pressure rolls are offset from the electrodes in the direction of the travel of the tube, and internal and external magnetic cores are used to provide a substantially closed magnetic circuit of sufficient length on each side of the electrode contact whereby the tendency of the current applied by the electrodes to flow around the back of the tube may be resisted to a considerable extent.

Figs. 16, 17 and 18 are diagrammatic, plan, side elevation and vertical cross section on the line a—a of Figs. 16 and 17, respectively, showing another modified form of my invention wherein an internal core and coil are used. The external core is omitted.

Figs. 19, 20 and 21 are diagrammatic, plan, side elevation and vertical cross section on the line a—a of Figs. 19 and 20, respectively, showing a preferred form of my invention wherein progressive flash welding may be effected by current conducted to the tube from roller electrodes and caused to flow across the seam, and involves the use of internal and external magnetic cores and a suitably positioned and energized coil on the internal core.

Figs. 22, 23 and 24 are diagrammatic, plan, side elevation, and vertical cross section on the line a—a of Figs. 22 and 23, respectively, of a modified form of my invention wherein the coil is positioned on the external core only. This form is very effective where the diameter of the tube is such that an internal coil cannot conveniently be used.

Fig. 25 is a side elevation, partly in section, of a machine embodying a preferred form of my invention.

Fig. 26 is a partial plan view of the machine shown in Fig. 25.

Fig. 27 is a vertical cross section taken in a plane indicated by the line 27—27 in Fig. 25.

Fig. 28 is a vertical cross section taken in a plane indicated by the line 28—28 in Fig. 25.

Fig. 29 is a vertical cross section taken in a plane indicated by the line 29—29 in Fig. 25.

Fig. 30 is an enlarged detail of a portion of Fig. 29.

Fig. 31 is a vertical cross section taken in a plane indicated by line 31—31 in Fig. 25.

Fig. 32 is a partial side elevation, partly in section, showing a modified arrangement of parts of the machine of Fig. 25.

Fig. 33 is a partial side elevation, partly in section, of a modified form of my invention.

Fig. 34 is a diagrammatic perspective drawing of apparatus similar to that of Fig. 25 or Fig. 32, and includes a wiring diagram.

In the preferred form of my invention I utilize roller electrodes and a welding transformer connected thereto such as are well known in the art and illustrated in Johnston Patent No. 1,388,434 or in my Patent No. 1,722,711, together with an internal magnetic core and an external magnetic core which provide a low reluctance path for a magnetic field capable of inducing an electromotive force in the pipe opposed to the electromotive force applied by the electrodes which tends to cause current to flow around the back half of the pipe. The edges of the pipe are maintained in spaced-apart relation between the electrodes and are brought together at a point beyond the electrodes in the direction of movement of the pipe, so that the welding current conducted to the pipe by the electrodes flows generally longitudinally of the pipe and then transversely across the seam in a zone of appreciable longitudinal extent compared to the zone or path of current flow of the heretofore practiced methods of contact resistance welding of tubing. The electrical resistance of the path between the electrodes and across the seam is thus considerably increased and a higher voltage must be applied to the pipe at the electrodes than is the case with contact welding as heretofore practiced. This means that a prohibitively large part of the total current would flow around the back of the pipe unless the proper steps are taken to resist, overcome or prevent such flow. I am able to minimize, or entirely prevent, the flow of current about the back half of the pipe by providing an internal, ferrous, magnetic circuit, preferably of laminated iron, and an external, ferrous, return magnetic circuit, also preferably of laminated iron. I preferably provide suitable electric coil means for developing a magnetic field in the internal and external cores. The magnetic field developed in the magnetic cores sets up a counter electromotive force in the wall of the pipe of sufficient magnitude to minimize or entirely prevent the flow of current from the electrodes around the back of the pipe.

I am aware that it has previously been suggested that an internal magnetic core will tend to prevent the flow of current around the back of a pipe being electrically welded when practicing stationary electric resistance welding, but as far as I am aware no one has previously realized the importance of the external, return magnetic circuit or core, or the possibility of utilizing an energized electric coil in connection with a magnetic core or cores in such a manner as to make possible in progressive welding the flow of welding current between the electrodes and across the seam through a path of comparatively high resistance or to make possible the use of the relatively high voltage which must be applied to the pipe at the electrodes to accomplish progressive flash welding or progressive welding where the effective welding current flows in a wide path or zone of appreciable longitudinal extent. In the practice of continuous, progressive electric resistance welding of tubing by the contact method, it has heretofore been impossible to cause a welding current to spread out and to flow across the seam in a heating zone of appreciable longitudinal extent because the necessarily increased voltage at the electrodes caused the current which flowed around the back of the pipe to increase so rapidly that it was impossible to properly heat the seam edges without excessive, or even prohibitive, losses and ruinous arcing and burning between the electrodes and the metal of the pipe.

My invention makes possible, in its preferred form, the practice of progressively flash welding longitudinal seams in pipes or tubes by the contact method by permitting the edges of the tube to be brought together in the requisite flash-welding relation or pressure at a point behind the electrodes in the direction of movement of the tube and by permitting the application of sufficient voltage to the tube to cause the proper flash heating current to flow across the seam, without losing an excessive amount of power in the flow of current around the back of the tube or requiring the electrodes to conduct an excessively large current to the tube.

In the practice of my invention, I control the length of the zone across which current flows, so that by spreading out, or elongating, the zone of current flow across the seam edges, at each

instant an appreciable length of seam is being heated by the instantaneous value of the alternating current then flowing. By the expression "an appreciable length of seam", I mean a perceptible or measurable length; the minimum practical length being several times the distance travelled by the tube during the duration of a single alternation or impulse of the welding current. Each point along the seam will thus be raised to substantially the same temperature. This length of flash-heating, current flow may be extended, depending upon the results desired and upon the diameter, thickness and material of the tube being welded and the welding speed. Thus if the flash-heating zone is two inches long and the welding speed is sixty feet per minute, any one point on the seam would pass through the zone of effective current flow for approximately one-sixth of a second. In this time some twenty impulses of 60 cycle alternating current will have flowed across the seam; the surface irregularities will be flashed or burned away, and a uniform heat will have been progressively developed in the seam edges, so that they will be at the proper temperature and in proper condition for the final upsetting and pressure application when the tube passes through the welding pressure rolls. So many different factors enter into the determination of and the establishment of the length of the flash heating zone or the length of the zone of effective, cross-seam current flow, that the best length may preferably be determined by trial.

The diagrammatic illustrations shown in Figs. 1 to 24, inclusive, comprise eight groups of three figures each. In each group there is shown a tube, or pipe, 1, being welded. The tube is represented as moving from left to right and as having a longitudinally extending open seam 2. The welded seam is indicated at 3. Roller electrodes 4, 4, positioned in the plane indicated by the line a—a, contact with the outside surface of the tube on opposite sides of the seam. Welding pressure rolls 5, 5 are diagrammatically illustrated. The center line of the welding pressure rolls 5, 5 is indicated by a line b—b in each of the four groups shown in Figs. 13 to 24, inclusive. In the four groups shown in Figs. 1 to 12, inclusive, the center line of the welding pressure rolls 5, 5 is indicated as being located on, or substantially on a line a—a in each group which indicates a plane through the center of the electrode rollers 4, 4. The other parts which are diagrammatically illustrated in some or all of the drawings, Figs. 1 to 24, inclusive, are an internal, laminated magnetic core, shown variously at 6, 6a, 6b, 6c, 6d, 6e and 6f, an external, laminated magnetic core, shown at 7a, 7b, 7c, 7d and 7e, an internal electric coil, shown at 8, 8a and 8b, and an external electric coil 9. The general position of the zone in which electric current flows across the seam edges to heat the edges to the welding temperature is indicated by the letter W in all of the groups shown by Figs. 1 to 24, inclusive.

My invention provides for effectively reducing or preventing the flow of current from the electrodes around the back of the tube, thereby causing substantially all of the current applied to the tube from the electrodes to flow in a path across the seam edges. My invention further makes possible the controlling of the length and characteristics of the heating or welding zone to produce a heating or welding zone of appreciable longitudinal length; that is to say, my invention makes possible the spreading out of the flow of current across the seam so that the current flows across the seam in a zone of appreciable longitudinal extent. This result is preferably achieved by suitably maintaining the edges of the seam spaced apart, bringing them into contact at a point beyond the center line of the electrodes, and positioning the welding pressure rolls in a plane still further removed from the center line of the electrodes.

Heretofore the only practice which has been used in progressive electric resistance welding of tubing by the contact method has been that illustrated in Figs. 1, 2 and 3. The center plane of the welding pressure rolls has been substantially in the plane of the center of the electrode rolls, and within my knowledge not more than one-half inch either way from coincidence. The current flowing across the seam from one electrode to the other and which is effective in heating the edges before the completion of the weld, has flowed in a very narrow zone. Figs. 1, 2 and 3 are intended to illustrate both the practice under the Johnston Patent No. 1,388,434 and under Parpart Patent No. 658,741.

In welding in accordance with the Johnston Patent No. 1,388,434, the current which is effective in heating the seam to develop welding temperature flows across the seam in a highly concentrated stream or narrow zone.

In the welding which was practiced under the Parpart Patent No. 658,741, the longitudinal extent of the zone of cross-seam current which was effective for heating the seam edges and the metal of the tube was also very short. The edges of the seam in Parpart welding were caused to come together between the electrodes at a point which formed the apex of comparatively widely diverging sides of a V formed by the seam edges. The flow of current which was effective in heating the edges took place in a zone directly between the electrodes, in which zone the seam edges were pressed together in the manner used when practicing stationary, upset electric resistance welding. To maintain this upset heating zone, the voltage impressed on the tube by the electrodes, even at the low speeds used, was such that tests indicated that thirty per cent of the total current conducted to the tube flowed around the back of the tube.

The use of an internal magnetic core such as illustrated in Figs. 4, 5 and 6 was tried experimentally by me in connection with the Johnston method of contact resistance welding of tubing. It might be expected that such a core might decrease the flow of current around the back of the tube, but I found that the power consumption with such a core is substantially the same as when no core is used and, therefore, such cores produced no advantageous result and were never used in the commercial production of tubing.

By the use of both external and internal magnetic cores as illustrated in Figs. 7, 8 and 9, I provide a substantially closed magnetic circuit, the air gap being kept practically as short as possible. In this manner comparatively small current flowing around the back of the tube will produce a magnetization of the cores to develop a counter electromotive force in opposition to the electromotive force which is conducted or applied to the tube from the electrodes 4, 4 and which tends to cause the waste current to flow around the back of the tube. This is valuable, when welding with the Johnston or Parpart relation between the center line of the electrodes and the center line

of the welding pressure rolls, in certain special cases where the material of the tube being welded, or the condition of the edges being welded, is such that best results can only be achieved by applying a considerably higher voltage across the electrodes than is normally used.

The use of an energized coil in conjunction with internal and external magnetic cores is illustrated in Figs. 10, 11 and 12. In this case an electromotive force may be positively and controllably induced in the tube by an energized coil 8. The induced electromotive force may readily be controlled both as to magnitude and phase relation with respect to the electromotive force applied to the tube at the electrode contacts, so that flow of current from the electrodes around the back of the tube may be substantially or entirely prevented. A substantially closed magnetic circuit is formed by the cores 6b and 7b.

Preferred forms of my invention, however, are diagrammatically illustrated in Figs. 13 to 24, inclusive, some of which are shown in greater detail in the subsequent figures of the drawings. These figures 13 to 24 relate to the progressive electric resistance welding of a tubular article by the contact method wherein the seam edges are maintained in spaced-apart relation between the electrodes 4, 4 and are caused to come into contact at a point beyond, or removed from the area of electrode contact with the tube in the direction of travel of the tube, in such manner that the current flows across the seam edges in a flash heating zone W of appreciable longitudinal extent. After the flash heating of the surfaces and the metal closely adjacent to the surfaces of the seam edges has been accomplished, the welding pressure rolls 5, 5 exert the required pressure to complete the weld. The process generally involves a flashing between the seam edges and a subsequent squeezing together of the heated edges similar to that used in the very extensively practiced method of stationary flash, resistance welding. It may also include a subsequent region or zone of current flow where the edges are pressed together in more intimate contact than is used in flash welding. It has heretofore been impossible to apply or conduct to a tubular article the requisite voltage for flash welding without excessively large current flowing around the back of the tube. My invention so restricts and overcomes the tendency of the current to flow around the back of the tube that sufficient current is forced to flow across the seam, and to flow in a zone of appreciable longitudinal extent, preferably not directly between the electrodes. This means that it is possible to apply to the electrodes a flash welding voltage that will be sufficiently high to cause proper flash welding or heating of the seam edges.

Flash resistance welding is accomplished very effectively by induction welding such as illustrated in my Patents 1,365,198 and 1,365,199. However, when welding by the induction method a considerable length of tube is unwelded or improperly welded at each end, particularly at the trailing end of the tube. By the use of my invention the longitudinal seam of the tube may be flash welded with a very short length of scrap at the ends. The flashing zone may be made short and the length of scrap at the trailing end will not be more than the length between the center line a—a of the electrodes 4, and the center line b—b of the welding pressure rolls 5, 5. In straight, contact welding as practiced under the Johnston and Parpart patents, the edges of the seam must be very carefully prepared, and the circumference of the unwelded tube, i. e., the width of the strip which is formed into the tube, must be held within very close tolerances. In flash welding, irregularities of the edge surfaces of the seam are much less troublesome, and, in general, the condition of the edge surfaces and the circumference of the open seam tube need not be quite so accurately maintained as is the case with Johnston and Parpart welding. When the current which is effective in heating the seam flows across the seam in a zone of appreciable longitudinal extent, slight imperfections or irregularities on the surfaces of the tube with which the electrodes contact, will not cause unwelded or imperfectly welded spots in the seam.

When using an energized coil on one or both of the magnetic cores with my invention, this coil need only consume the power required to develop a suitable electromotive force in the wall of the tube to buck or oppose the applied electromotive force The coil supplies little, or none of the power which goes into the actual heating of the edges. Because of this, the coil used may be of much smaller electrical capacity than that required for induction welding. This means that with any one frequency, an internal coil can be used with smaller tubes than in the case of induction welding. By increasing the frequency above 60 cycles per second, still smaller tubes can be welded when using an internal coil because the cross-sectional area of the core may be smaller.

In Figs. 25 to 31, inclusive, I have shown, somewhat diagrammatically, a machine for carrying out my invention. A tube or pipe 1 has a longitudinal open seam 2, the welded seam being indicated by the numeral 3. A base or bed of the machine is shown at 10. A pair of roller electrodes 4, 4 are arranged to contact with the outside of the tube on opposite sides of the seam. The electrodes 4, 4 are suitably supported above the tube by supporting members indicated generally at 11. Any suitable welding transformer may be mounted in the support 11. Transformer secondary terminals are indicated at 12 as extending downwardly from the transformer and forming a support for a shaft 13 on which the electrodes 4, 4 are mounted and insulated from each other and from the shaft 13. Brush holders 14 and brushes 15 serve to carry the large amperage welding current from the transformer terminal legs 12, to the roller electrodes 4, 4.

Rolls 16 and 17 are suitably power driven and serve to assist in progressively and continuously moving the tube through the machine. Rolls 16 and 17 are located at the entering end of the machine. The roll 16 is provided with a central fin or disk 18 which enters between the unwelded edges of the open seam 2 and serves as a seam guide and a seam spreading means. The disk 18 thus acts to properly position and guide the seam of the oncoming tube and also insures proper spacing between the seam edges at the plane in which the rolls 16 and 17 are located. Bearing housings 19, 19 serve to support the rolls 16 and 17. Rolls 20, 20 located at the discharge end of the machine correspond to rolls 16 and 17 at the entering end of the machine. Rolls 20, 20 are suitably power driven and are supported in housings 21, 21. Mechanism for driving the rolls 16 and 17 and 20, 20 is not shown as such mechanism is well known and thoroughly understood by those skilled in the art.

A longitudinally adjustable seam-guiding disk 22 is supported by brackets 23 and is mounted on

Defendants' Exhibit DX-C-Tab 4

a shaft 24. The brackets 23 are secured to the base 10 by bolts 25. The bolts 25 extend into T-slots 26 in the base 10. The T-slots 26 are longitudinally extending, and as a result, the seam-spreading and seam-guiding disk or roller 22 may be adjusted longitudinally, i. e., in the direction of the axis of the tube, to suit the requirements of the particular tube and the manner in which the seam edges are caused to come together. By moving the seam spreading guide 22 in the direction of movement of the tube, the seam edges may be held apart so that they approach each other at a wider angle. Conversely, if the disk roller 22 is moved in the direction opposite to the direction of the tube movement, the edges of the seam will approach each other more gradually.

I find it convenient to describe the approaching seam edges as forming a V, the apex of the V being the point where the edges finally contact with each other. When the edges are caused to come together more abruptly, the condition existing may be described by saying there is a greater angle between the approaching (converging) sides of the V. When the seam edges come together more gradually, the condition may be described by saying that there is a smaller angle between the approaching (converging) sides of the V. Disks 22 of selected thicknesses may be used as additional means for controlling the space between the seam edges and the angle of convergence of the sides of the V formed by the seam edges.

Vertical axis rolls 30, 30 are positioned close to the heating and welding zone. The rolls 30, 30 are mounted on shafts 32, 32 and are supported on transverse slides 33, 33; the slides 33, 33 being mounted in slideway blocks or housings 34, 34. The rolls 30, 30 may be adjusted transversely of the tube, towards or away from the axis of the tube, by adjusting screws 35, 35. The rolls 30, 30 are shown as idle rolls, but if desired they may readily be power driven. The adjustment of the rolls 30, 30 serves to determine the opening between the seam edges at the plane in which they are located and assists in controlling and fixing the location of the point at which the edges come into contact with each other. The rolls 30, 30 also assist in guiding the tube into and through the heating and welding zone, support substantially the entire outer circumference of the tube, help to hold the edges in proper alignment for their subsequent accurate abutment, and tend to prevent overlapping and buckling of the seam edges.

Welding pressure rolls 36, 36 are mounted on vertical shafts 37, 37. These are preferably idle rolls. The rolls 36, 36 may be termed pressure rolls, or welding rolls. They serve to form the welding throat where the final circumferential pressure is exerted on the tube to squeeze the edges together and complete the weld. Rolls 36, 36 are supported by slide blocks 38, 38 which are mounted in transverse slideway members 29, 29 and may be adjusted transversely of the tube towards or away from the axis of the tube, by means of adjusting screws 40, 40. The members 39, 39 are suitably mounted in longitudinal slideway members 41, 41 and may be adjusted longitudinally, or axially, of the tube by means of adjusting screws 42, 42. The transverse adjustment of the rolls 36, 36 serves to provide the proper welding pressure take-up, or upset at the seam edges. This transverse adjustment is used to properly correlate the pressure between the seam edges with the other factors involved in producing the desired weld. The longitudinal or axial adjustment of the rolls 36, 36 serves to properly position the point or plane of final welding pressure with respect to the vertical transverse plane through the center of the electrodes 4, 4, and may be utilized to change the angle between the converging sides of the V formed by the converging seam edges, change the location of the point of first contact of the seam edges which forms the apex of the V, and change the length and character of the heating zone where the current which is effective in heating the seam edges flows across the seam. The longitudinal adjustment of rolls 36, 36 is therefore very important in obtaining a flash welding zone of the desired length and characteristics. The dot-dash outlines 43, 43 and 43', 43' in Fig. 26 indicate approximately the extreme positions to which the rolls 36, 36 may be moved away from or towards the central plane of the electrodes in the particular apparatus shown.

A longitudinally extending anchor bar or rod 44 is suitably supported and positioned in known manner inside of the path of travel of the tube by an externally-supported, plate-like member, not shown. The bar 44 is suitably connected to an extension bar or plate 45 which extends substantially to the plane of the external rolls 30, 30. In the plane of the rolls 30, 30, a seam guiding disk 46 is supported on brackets 47, 47 which are mounted on the bar 45. As shown in Fig. 27, the internal roller or disk 46 is preferably formed of two halves insulated from each other by a disk of insulation 48, the two halves being mounted on a common shaft 49 and suitably insulated from the shaft 49 and from the brackets 47, 47. The two halves which form the disk 46 are provided with hubs or roller extensions 50, 50 adapted to bear against the inside surface of the tube closely adjacent to, and on each side of the open seam. This disk roller 46 serves very effectively in conjunction with the external rolls 30, 30 to guide and hold apart the seam edges and to hold the seam edges in the proper alignment for their subsequent accurate abutment. If desired, this disk roll 46 may be made radially adjustable in known manner by providing suitable eccentric mountings for the shaft 49. I prefer to mount the disk 46 on the shaft 49 with a slight amount of axial play, as shown in Fig. 27 but in some cases it may be desirable to eliminate this axial play or movement and use the disk 46 as a means for maintaining the bar 45 and the members supported thereby in the desired and fixed relation to the seam of the tube.

Substantially in the plane of the external rolls 30, 30, I preferably provide circumferentially spaced, adjustable internal rollers 51, as shown in detail in Fig. 28. The rollers 51 are supported in a two-piece bracket 52, the two halves of which are supported by the bar 45 and are suitably insulated from each other and from the bar 45 by insulation 53. Each of the rollers 51 is provided with a shaft 54 which is supported in eccentric bushing 55. Bushings 55 are secured by set screws 56. Thus the internal rollers may be adjusted towards and away from the axis of the tube, i. e., towards and away from the inside surface of the tube. The rollers 51 act in conjunction with the external rollers 30, 30 and the internal disk roll 46 to establish and maintain the desired spacing between the seam edges, and to govern the angle of convergence of the seam

edges and the location of the point where the seam edges first contact with each other. The rolls 51 also serve to assist in properly supporting and positioning the bar 45 and the parts and members secured thereto and act to prevent inward collapse of the tube.

Substantially in a vertical plane through the center of the electrode rolls 4, 4, I prefer to provide another series of circumferentially spaced, adjustable internal rollers 57, and 58, 58, shown in detail in Figs. 29 and 30. The internal roller 57 is made up of two halves insulated from each other by insulation 59 and 60, and is mounted on a shaft 61. The shaft 61 is supported in suitable brackets 62, 62 by means of eccentric bushings 63, 63. The brackets 62, 62 are suitably bolted together and mounted on a core 6*g*, hereinafter referred to. I preferably provide a central groove 64 in roller 57 so that the seam edges will not be short circuited by the metal of one half of the roller 57. Rollers 57, 58, 58, brackets 62, 62, and the shafts for the rollers 57 and 58 are preferably made of non-magnetic material. The rollers 58, 58 are provided with similar eccentric bushings. The vertical plane including rollers 57 and 58, 58 is preferably located in substantially the same vertical plane as the centers of the electrode rollers 4, 4. The position of the roller 57 with respect to the central plane of the electrodes may be varied slightly to obtain the best contact between the electrodes and the tube. Such variation may be readily obtained by longitudinal adjustment of the rod 44, which may be readily made in a manner well known in the art. The approximate centers of the contact areas of the electrodes 4, 4 with the tube are shown at 65, 65 in Fig. 26.

Additional internal rollers 66 are also provided in a plane beyond the rollers 57 and 58, 58 and are supported by the bar 45 in a manner similar to rollers 51. The rollers 66 are adjustable by means of eccentric bushings in the same manner that the rollers 51 are adjustable.

An internal magnetic core 6*g* extends longitudinally inside of the tube from a point considerably in advance of the contact area of the electrodes with the tube to a point considerably beyond the contact area of the electrodes in the direction of tube movement. This magnetic core 6*g* is supported by bar 45 and is preferably made of thin laminations of electrical sheet steel. A two-part internal coil 8*c* and 8*d* surrounds the internal magnetic core 6*g*, 8*c* being the front coil and 8*d* the rear coil.

An external magnetic core 7*f* is supported on brackets 67 which are mounted on the base 10. The core 7*f* is formed of laminated electrical sheet steel, is secured to the brackets 67 by bolts 68 and is insulated from the brackets 67 by suitable insulation 69. This external magnetic core 7*f* extends parallel to the axis of the tube and substantially opposite the internal magnetic core 6*g*. The ends of the internal magnetic core 6*g* are provided with polar extensions 70 and 71. Opposite the poles 70 and 71 are poles 72 and 73, respectively, of the external core 7*f*. The front poles 70 and 72 preferably extend to points close to the inside and outside surfaces, respectively, of the tube, and are thus separated by as small an air gap as mechanically and commercially practical to permit the passage of the tube between the poles. The rear poles 71 and 73 are likewise preferably positioned with a short air gap between them. The external and internal magnetic cores thus complete a substantially closed magnetic circuit of relatively low magnetic reluctance, the external magnetic core serving as a return magnetic circuit of low magnetic reluctance for the magnetic field developed in the internal magnetic core.

Electrical connections or conductors 74, 75, 76 and 77 are preferably carried into the tube at the point where the bar 44 is externally supported and extend along the bar 44 to the coils 8*g* and 8*d*. Conductors 74 and 75 are connected to the front and rear ends, respectively, of the front coil 8*c*. Conductors 76 and 77 are connected to the front and rear ends, respectively, of the rear coil 8*d*. These connections are shown in Figs. 25 and 34.

At the rear end of the bar 45 there is mounted a bracket 78 which carries internal rollers 79 and 80, which are adjustable radially or towards and away from the axis of the tube by means of adjustable eccentric bushings. The rollers 79 and 80 are located substantially in the plane of the rolls 20, 20 and serve to further support the bar 45 and the parts connected thereto. The roller 79 in conjunction with the top external roll 20 may be used to roll down the weld. The internal roller 80, positioned immediately above the lower external roll 20, serves to limit any downward movement of the supporting bar 45 when tubing is not present between the rolls.

I find it generally desirable to provide the internal rollers 57 and 58, 58, which are located substantially under the electrodes 4, 4, in order to properly support the tube at this point to prevent the collapse of the top portion of the tube under the electrode contact pressure, and to assist in holding the seam edges apart between the electrodes 4, 4. There is a tendency for the tube to collapse under the pressure of the electrode contact when the edges are not in contact with each other between the electrodes. In some cases these internal rollers may be omitted, particularly when the pressure rollers 36, 36 are positioned fairly close to the electrodes, or when a tube having a relatively thick wall is being welded. This condition is shown in Fig. 32 wherein internal coils 8*e* and 8*f* are spaced apart only a distance sufficient for proper insulation. The other parts shown in Fig. 32 are the same as the parts shown in Figs. 25 and 26. It will be obvious that a single internal coil may be used instead of the two-part coil shown in Fig. 32.

Additional support for the tube under the electrodes 4, 4 may be provided by the use at this point of an additional set of external rolls, not shown in the drawings. Suitable rolls for this purpose are well known in the art, and they may readily be used when the pressure rolls 36, 36 are not located close to the central plane of the electrodes 4, 4.

By providing a properly positioned and proportioned magnetic circuit of low magnetic reluctance made up of an internal magnetic core extending longitudinally inside of the tube from a point in advance of the electrode contact areas to a point behind the electrode contact areas and an external magnetic core outside of the tube, substantially opposite the internal magnetic core it is possible to provide a magnetic circuit of such low reluctance that the current flow around the back of the tube from the electrodes may be to a considerable extent minimized without the use of any separately energized coils for developing a magnetic field in the internal core. This form is shown in Fig. 33. The parts shown in Fig. 33 are similar to the corresponding parts in Figs. 25 and 26, except for the absence of the

internal coils. This is similar to the condition illustrated diagrammatically in Figs. 13, 14 and 15. When welding with the arrangement shown in Figs. 25 and 32, for example, where an energized coil or coils are used, the coils may be compared to the primary winding of a transformer and the tube may be compared to a single-turn secondary of the transformer, the voltage developed in the secondary being of such phase relation and such magnitude as to oppose the flow of current which tends to go around the back of the tube as a result of the voltage applied to the opposite sides of the seam by the electrodes. When the arrangement illustrated in Fig. 33 is used, the tube may be compared to an auto-transformer, the body of the tube serving as both primary and secondary of the transformer, as does the single winding of an auto-transformer. Thus, with a substantially closed magnetic circuit, a comparatively small amount of current flowing around the back of the tube from the electrodes may develop a sufficient secondary or counterelectromotive force in the tube to prevent excessive current flowing around the back of the tube, even though a voltage sufficiently high to maintain a flash heating zone of appreciable extent is applied to or conducted to the tube by the electrodes, but the use of an energized coil is preferable.

In the best practice of my invention, it is important to be able to control and regulate the angle of convergence of the seam edges, the location of the point of first contact between the edges, and the character, location and extent of the pressure relation between the edges prior to and during the final application of welding pressure. These factors may be controlled and regulated by the use either singly or in combination with one another of changes or adjustments of the rolls 16 and 17, the fin 18, the seam-guiding disk 22, rolls 30, 30, welding rolls 36, 36, disk roller 46, rollers 51, rollers 57 and 58, 58 and rollers 66.

To obtain the best results in the practice of my invention, the two electrodes 4, 4 should be spaced farther apart or otherwise so constructed that their contact areas with the surface of the tube do not extend as close to the seam as has heretofore been required in the practice of Johnston or Parpart welding. This wider spacing between the contact areas assists in producing a spreading out of the path of current flow across the seam. The use of such a wider space between the current-conducting contact areas on the opposite sides of the seam will cause more current to follow the path around the back of the tube unless the means which I have disclosed are used to prevent or resist such current flow. In fact, with such a wider space between the areas where current is conducted to the tube by the electrodes when not using my invention, the proportion of the total current which flows around the back of the tube is so large that it may be impossible to cause enough current to flow across the seam edges to heat them to the required welding temperature. Since the use of a wider space between the contact areas is not only possible but highly desirable, another important result is attained, namely, that the seam may weave from side to side or vary more from the exact central position between the electrodes without causing trouble in the welding.

My invention is illustrated diagrammatically and a wiring diagram of the electrical circuits which I prefer to use is shown in Fig. 34. Fig. 34 illustrates an arrangement similar to that shown in Figs. 25 and 32 wherein internal and external laminated magnetic cores are used with a two-part internal coil. A suitable single phase power supply is connected through a transformer or induction regulator, not shown, to leads 81 and 82 of an auto-transformer 83. Leads 84, 84 from the auto-transformer 83 are connected to a primary winding 85 of a welding transformer. The welding transformer is provided with a single turn secondary winding 86 which is capable of carrying the very large currents required for welding. The secondary 86 of the welding transformer is connected to roller electrodes or other suitable current conducting members which contact with the tube at the areas 87, 87. The seam edges are spaced apart between the electrodes so that the heating and welding current flowing from the electrodes must flow generally longitudinally of the tube in the direction of tube movement and then across the seam behind the electrodes. The internal coil means is made up of two parts, 8*g* and 8*h*, which may be externally connected either in series or in parallel by means of switches 88 and 89. Leads 90 and 91 which supply power to the internal coil means 8*g* and 8*h* are preferably arranged to be connected to one of the three phases of a three-phase power line, one phase of which is connected to the leads 81 and 82 which supply power to the welding transformer. The leads 90 and 91 are connected to an auto-transformer 92. Conductors 93, 93 from the auto-transformer 92 are connected to a reversing switch 94. From the reversing switch 94, connections 95 and 96 lead to the coils. In series with the coils I preferably provide a variable or adjustable inductance 97 and/or a variable or adjustable condenser 98. As shown in solid lines in Fig. 34 switch 88 connects conductors 74 and 76, and the switch 89 connects conductors 75 and 77 so that the two coils 8*g* and 8*h* are connected in parallel. When, as shown in dot-dash lines at 88' and 89', switch 88 is open and switch 89 connects conductors 75 and 76, the coils 8*g* and 8*h* are connected in series. By suitably choosing the phase of the three-phase power supply which is connected to the auto-transformer 92 and by suitably adjusting the inductance 97 or the condenser 98, I am able to maintain any desired phase relation between the voltage induced in the pipe and the voltage applied to the pipe by the electrodes. This phase relation may be obtained accurately by the use of an oscillograph. In practice, however, the phase relation may be substantially correctly established by choosing the proper one of the three phases of the power supply and adjusting the series reactance in the lines 95 and 96, while maintaining all other conditions constant, and maintaining a constant voltage across the electrodes, until the condition is reached where the maximum heat is being developed in the seam. When this is the case, it is obvious that substantially a minimum of power is being lost in current flow around the back of the tube. The voltage applied to the internal coils 8*g* and 8*h* should also be varied either by an auto-transformer 92 or an induction regulator, not shown, until proper conditions are established. This voltage, however, should not be raised to a point where an abnormally large current is caused to flow through the coils 8*g* and 8*h*. This can be determined by electrical instruments in the circuit. The coils 8*g* and 8*h* need not carry a particularly large current because it is not necessary

that they assist the current from the electrodes in any way in developing a flow of heating current across the seam.

When using my invention, the total current which may be conducted by the electrodes into a tube, instead of including a large amount of waste current, becomes, to a large extent, effective welding current. Thus, although limitations in the current carrying capacity of the apparatus which comprises the circuit of the welding current, such as the area of contact between the electrodes and the tube, impose a limitation upon the total current which may be safely carried, the actual welding current (current which flows across the seam) may be greatly increased without changing the total current which flows in the circuit.

By my invention, the large, back-of-tube waste current which has heretofore been unavoidable when progressively welding a longitudinal seam in tubing, particularly the prohibitively large waste current which occurs when flash welding voltages are used, does not have to be supplied by the welding transformer or other source of low voltage welding current through sliding contacts and electrodes. By using an energized induction coil, energized at a relatively high voltage, I am, in effect, able to supply the waste power at a high voltage without requiring such power to be conducted at low voltage through brushes, electrodes or other parts of the apparatus which, of necessity, must carry the low voltage, high-amperage current which flows across the seam to do the actual welding.

It will be obvious to those skilled in the art that numerous other modifications of the structures shown and described may be used; for example, coils may be placed on both the internal and the external cores, or if desired each section of a two-part coil may be energized from an independent circuit.

In considering positions along the tube and in the machine, the term "in advance" is used to mean on the side from which the tube is moving, that is, toward the entering side of the machine. The terms "behind" or "beyond" are used to mean in the direction of movement of the tube, that is, toward the exit side of the machine.

I claim:

1. The method of progressive, electric resistance welding of a longitudinal seam in tubing, which comprises conducting electric current to the tube by contact on each side of the seam cleft in advance only of the meeting point of the seam edges from a source capable of supplying current of suitable amperage for welding, causing the edges of the seam to move progressively together at a point beyond the region where said current enters the tube, and inducing in the body of the tube a circumferential electromotive force opposing the flow of current around the back of the tube from said source, thereby largely limiting the flow of said conducted current to a path through the metal of the tube and across the seam in the region where the seam edges move together.

2. The method of progressive electric resistance welding of a longitudinal seam in a tubular article, which comprises progressively moving the tubular articles parallel to the seam, conducting electric current to the tubular article by contact on each side of the seam cleft at a zone where the edges of the seam are spaced apart, causing said edges to meet progressively at a point beyond said zone of contact in the direction of movement of the tubular article to establish and maintain a flash heating zone of appreciable longitudinal extent wherein said electric current may flow across the seam edges, developing a magnetic field inside of said tubular article capable of inducing within the body of said tubular article an electromotive force substantially opposed around the back of said tubular article to the applied potential which causes said electric current to flow and variable with respect to said applied potential, maintaining said induced electromotive force at such magnitude and phase relation as substantially to prevent flow of said electric current around the back of said tubular article, and applying welding pressure to said tubular article.

3. The method of progressive electric resistance welding of a longitudinal seam in tubing which comprises progressively moving the tubing in a direction parallel to the seam, applying from an external source by members making contact at relatively high pressure with the tube on opposite sides of the seam in advance only of the meeting point of the edges of the seam, an electromotive force suitable for welding, maintaining the edges of the seam in such spaced-apart relation between said contact members as to prevent cross-seam current flow at the zone of contact of said members, applying internal pressure for supporting the wall of the tube to resist the external pressure of the contact members on the tube, bringing the edges close enough together to permit cross-seam current flow at a point beyond said contact zone in the direction of movement of the tube, and establishing an electromotive force around the back of the tube substantially in phase opposition to said first-named electromotive force and of substantially the same magnitude as said first-named electromotive force.

4. In apparatus for the progressive, electric resistance welding of a longitudinal seam in tubing, means for progressively moving the tubing parallel to the seam, a welding transformer, current conducting contact members electrically connected to said welding transformer and adapted to contact with the surface of a relatively short portion of the length of said tubing on opposite sides of the seam to be welded and to conduct impulsive welding current to said tubing, an energized electric coil inside of said tubing, the axis of said coil being substantially parallel to the axis of said tubing, said coil being positioned substantially opposite said contact members and extending axially from a point in advance of the contact areas of said contact members to a point behind said contact areas in the direction of travel of said tubing, means for energizing said coil with impulsive current whereby the current flowing in said coil flows at substantially every instant substantially in the same circumferential direction that current tends to flow around the back of said tubing from said contact members, and means for pressing the edges of the seam together.

5. In apparatus for the progressive, electric resistance welding of a longitudinal seam in tubing, a welding transformer, current conducting contact members electrically connected to said welding transformer and adapted to contact with the surface of the tubing on opposite sides of the seam to be welded and to conduct impulsive welding current thereto, a longitudinally disposed magnetic core inside of said tubing, said core extending from a point in advance of the contact areas of said contact members to a point behind said contact areas in the direction of travel of said tubing, an electric coil adapted when ener-

gized to develop a magnetic field of force in said magnetic core, said coil and said magnetic core being adapted to cause the magnetic lines of force of said magnetic field to extend in a substantially axial direction and to extend in the same direction at any one instant from a point in advance of said contact areas to a point behind said contact areas in the direction of tube travel, means for progressively moving said tubing in a direction parallel to the seam, and means for pressing the edges of the seam together.

6. In apparatus for the progressive, electric resistance welding of a longitudinal seam in tubing, a welding transformer, means for supplying alternating current from the opposite terminals of said welding transformer by contact to opposite sides of the seam to be welded, means for substantially preventing the flow of current around the back of the tubing comprising an internal magnetic core inside of said tubing, said core extending from a point in front of to a point behind the control areas of said current-supplying means with said tube, an external magnetic core outside of the tubing opposite said internal magnetic core, means for maintaining a spaced-apart relation between the edges of the seam between the contact areas of said current-supplying means, means progressively moving said tubing in a direction parallel to the seam, and means for causing said seam edges to come together at a point beyond said contact areas in the direction of movement of the tubing.

7. In apparatus for the progressive, electric resistance welding of a longitudinal seam in tubing, a welding transformer, means for supplying alternating current from opposite terminals of said welding transformer by contact to opposite sides of the seam to be welded, means for substantially preventing the flow of current around the back of the tubing comprising an internal magnetic core inside of said tubing, said core extending from a point in front of to a point behind the contact areas of said current-supplying means, an external magnetic core outside of the tubing opposite said internal magnetic core, electric coil means adapted when energized to develop a magnetic field of force in said cores, means for maintaining a spaced-apart relation between the edges of the seam between the contact areas of said current-supplying means, means for progressively moving the tubing in a direction parallel to the seam, and means for causing said seam edges to come together at a point behind said contact areas in the direction of movement of the tubing.

8. In apparatus for the progressive electric resistance welding of a longitudinal seam in tubing, a pair of roller electrodes contacting with the surface of the tube on opposite sides of the seam, means for maintaining said seam edges spaced apart between said electrodes, means for causing said edges to come together at a point behind the plane of the center of said electrodes, a longitudinally extending magnetic core supported inside of said tube, said core extending longitudinally in both directions from the region of contact of said electrodes with said tube, induction coil means adapted to develop when energized a magnetic field of force in said core, and means for progressively moving said tube in a direction parallel to the same.

9. In apparatus for the progressive, contact, electric resistance welding of a longitudinal seam in tubing, means for progressively moving the tubing in a longitudinal direction, current conducting contact members adapted to contact with the surface of the tubing on opposite sides of the seam to be welded and energized to conduct impulsive welding current thereto at a flash welding voltage, said contact members being relatively widely spaced apart across the seam whereby substantial lateral weaving of the seam between said contact members is permissible, means adapted to establish a flash-heating relation between the seam edges in a zone of appreciable longitudinal extent, and means for substantially preventing the flow of current from said contact members around the back of the tube, comprising means for inducing in the body of said tube an electromotive force tending to cause current to flow substantially circumferentially in said tube around the back of said tube and in substantially the opposite direction to that in which the current tends to flow around the back of said tube from said contact members.

10. In apparatus for the progressive, electric resistance welding of a longitudinal seam in tubing, a welding transformer, a pair of roller electrodes electrically connected to said transformer, said electrodes being adapted to contact with the surface of the tubing on opposite sides of the seam to be welded and to conduct impulsive welding current thereto, said electrodes being electrically a relatively long distance apart across the seam, and means for substantially preventing the flow of current from said electrodes around the back of the tubing comprising an internal magnetic core inside of said tubing, said core extending from a point in advance of the contact areas of said electrodes to a point behind said contact areas in the direction of travel of the tubing, electric coil means adapted when energized to develop a magnetic field of force in said core, the electric resistance of the path between said contact areas and across said seam being such that an excessively large amount of current would flow around the back of the tubing if said core and coil means were not present, means for progressively moving the tubing in a direction parallel to the seam, and means for pressing the edges of the seam together.

11. In apparatus for the progressive, electric resistance welding of a longitudinal seam in tubing, means for supplying alternating current from opposite terminals of a supply circuit by contact to opposite sides of the seam to be welded, and means for substantially limiting the flow of current around the back of the tubing comprising an internal magnetic core inside of said tubing, said core extending from a point in front of to a point behind the contact areas of said current-supplying means, and an external magnetic core outside of the tubing opposite said internal magnetic core, the space between said cores being shorter at their ends than at intermediate points, means for progressively moving the tubing in a direction parallel to the seam, and means for pressing the edges of the seam together.

12. In apparatus for the progressive, electric resistance welding of a longitudinal seam in tubing, means for supplying alternating current from opposite terminals of an electric supply circuit by contact to opposite sides of the seam to be welded, means for substantially preventing the flow of current around the back of the tubing comprising an internal magnetic core inside of said tubing, said core extending from a point in front of to a point behind the contacts areas of said current-supplying means, an external magnetic core outside of the tubing opposite said in-

ternal magnetic core, the space between said cores being shorter at their ends than at any intermediate point, electric coil means adapted when energized to develop a magnetic field of force in said cores, means for varying the phase relation between the current flowing in said electric coil means and said alternating current supplied by contact, means for varying the magnitude of the voltage impressed on said coil, means for progressively moving said article in a direction parallel to the seam, and means for pressing the edges of the seam together.

13. In apparatus for the progressive, electric resistance welding of a longitudinal seam in tubing, a welding transformer having primary and secondary windings, a pair of roller electrodes electrically connected to said secondary winding and adapted to contact with the surface of the tube to be welded on opposite sides of the seam, magnetic core means extending longitudinally of said tube in the region of contact of said electrodes with said tube, said core means having a portion inside of said tube and a portion outside of said tube opposite said inside portion, and an electric coil adapted when energized to develop a magnetic field of force in said core means, said electrodes and said core means being relatively so disposed and so energized that the electromotive force induced in a circumferential path in said tube by the lines of force in the energized core means, is substantially opposed in direction to the electromotive force which is applied to said tube by said electrodes and which tends to cause current to flow in a circumferential path around the back of said tube, means for progressively moving said tube in a direction parallel to the seam, and means for pressing the edges of the seam together.

14. The method of progressive, electric resistance welding of a longitudinal seam in tubing wherein welding current is developed in an external source such as a welding transformer and applied to the tube by current-conducting, contact members, which comprises the steps of moving the tube progressively in a direction parallel to the seam to be welded, continuously conducting by contact, at a flash-welding voltage, a high-amperage alternating current to the tube on opposite sides of said seam at contact areas relatively widely spaced apart across the seam whereby substantial lateral weaving of the seam between the contact areas is permissible, inducing within the tube an alternating electromotive force which tends to cause current to flow circumferentially around the tube throughout the entire length of the portion of the tube to which said high-amperage current is conducted, said electromotive force being of such instantaneous magnitude and direction as to reduce materially the flow of said high-amperage current around the back of the tube and to confine said high-amperage current substantially to a path which crosses the seam to be welded, maintaining a flash-welding relation between the seam edges throughout a zone of appreciable longitudinal extent in said path of cross-seam current, and pressing said edges together progressively to complete the weld at a point near the end of said zone in the direction of movement of said tube.

15. In apparatus for the progressive electric resistance welding of a longitudinal seam in a tubular article, an external source of welding current, a pair of electrodes adapted to conduct electric current to said article from said source, means for maintaining the seam edges apart between the contact areas of said electrodes with said article, means for bringing the seam edges together at a point behind said contact areas in the direction of movement of said article, a longitudinally extending magnetic core supported inside of said article, said core extending longitudinally in both directions from said contact areas, induction coil means adapted to develop when energized a magnetic field of force in said core, means for varying the phase relation between the current flowing in said induction coil and the current conducted to said article by said electrodes, means for varying the magnitude of the voltage impressed on said induction coil, and means for progressively moving said article in a direction parallel to the seam.

16. The method of progressive, electric resistance welding of a longitudinal seam in tubing which comprises causing the tube to move longitudinally in a direction parallel to the seam, conducting a low-voltage, large amperage alternating current to the tube by contact in advance only of the meeting point of the seam edges, whereby said current tends to flow across the seam in only one direction at any one instant, inducing within the body of the tube from a separate source of relatively high voltage electrical energy a circumferential difference of potential substantially opposed around the back of the tube to the potential of said current applied by contact and of such magnitude and phase as substantially to confine the flow of said current to a path across the seam whereby substantially the entire current applied to the tube by contact will be effective in heating the seam edges and whereby substantially the entire heating of the seam edges will be effected by said current in the region where said current flows across the seam, and pressing the seam edges together.

17. In apparatus for the progressive, electric resistance welding of a longitudinal seam in tubing, a welding transformer, means for supplying alternating current from opposite terminals of said welding transformer by contact to opposite sides of the seam to be welded, means for substantially preventing the flow of current around the back of the tubing comprising an internal magnetic core inside of said tubing, said core extending from a point in front of to a point behind the contact areas of said current-supplying means, electric coil means adapted when energized to develop a magnetic field of force in said core, means for maintaining a spaced-apart relation between the edges of the seam between the contact areas of said current-supplying means, means for progressively moving the tubing in a direction parallel to the seam, and means for causing said seam edges to come together at a point behind said contact areas in the direction of movement of the tubing.

18. In apparatus for the progressive, contact, electric resistance welding of a longitudinal seam in metal tubing wherein substantially the entire welding current is conducted to the tube by contact at relatively short zones on each side of the seam, a welding transformer having primary and secondary windings, current conducting contact members electrically connected to the secondary of said welding transformer and adapted to contact with said tube on opposite sides of the seam to be welded and to apply a potential difference across the seam cleft, an electric coil inside the path of movement of said tube, said coil being adapted when energized to induce a circumferential electromotive force in the wall of said tube

Defendants' Exhibit DX-C-Tab 4

throughout a zone extended longitudinally of the tube in each direction from the region of contact of said electrodes with said tube, the direction of said electromotive force being, at each instant, the same along the entire extent of said zone, means for maintaining said electromotive force at such magnitude and phase relation as substantially to prevent flow of current around the back of said tube, means for progressively moving said tube in a direction parallel to the seam, and means for pressing the edges of the seam together.

19. In apparatus for the progressive, electric resistance welding of a longitudinal seam in tubing, a welding transformer, current conducting contact members electrically connected to said welding transformer and adapted to contact with the surface of the tubing on opposite sides of the seam to be welded and to conduct impulsive welding current thereto, a longitudinally disposed magnetic core inside of said tubing, an electric coil so constructed and arranged as to develop when energized a magnetic field of force in said magnetic core, said coil and said magnetic core being so constructed and arranged as to cause the magnetic lines of force of said magnetic field to extend in a substantially axial direction and to extend in the same direction at any one instant from a point in advance of the contact areas of said contact members to a point behind said contact areas in the direction of tube travel, means for progressively moving said tubing in a direction parallel to the seam, and means for pressing the edges of the seam together.

20. In apparatus for the progressive, electric resistance welding of a longitudinal seam in tubing, a welding transformer, current conducting contact members electrically connected to said welding transformer and adapted to contact with the surface of the tubing on opposite sides of the seam to be welded and to conduct impulsive welding current thereto, a magnetic core, an electric coil so constructed and arranged with respect to said core as to develop when energized a magnetic field of force in said magnetic core, said coil and said magnetic core being so constructed and arranged as to cause the magnetic lines of force of said magnetic field to extend in a substantially axial direction inside of said tubing and to extend in the same direction at any one instant from a point in advance of the contact areas of said contact members to a point behind said contact areas in the direction of tube travel, means for progressively moving said tubing in a direction parallel to the seam, and means for pressing the edges of the seam together.

21. In apparatus for the progressive, electric resistance welding of a longitudinal seam in tubing, a welding transformer, contact members for supplying alternating current from opposite terminals of said transformer by contact to opposite sides of the seam to be welded, and means for substantially limiting the flow of current around the back of the tubing comprising an electric coil adapted when energized to induce a circumferential electromotive force in the wall of said tubing throughout a zone extending longitudinally of the tubing in each direction from the region of contact of said contact members with said tubing, the direction of said electromotive force being, at each instant, the same along the entire extent of said zone, means for progressively moving the tubing in a direction parallel to the seam, and means for pressing the edges of the seam together.

22. The method of progressive electric resistance welding of a longitudinal seam in tubing which comprises applying to the opposite sides of the seam from an external source an electromotive force of sufficient magnitude to establish a zone of cross-seam current flow of appreciable longitudinal extent, maintaining a flash welding relation between the seam edges throughout a portion of the longitudinal extent of said zone of cross-seam current flow, inducing within the wall of the tube an electromotive force substantially circumferentially opposed to said applied electromotive force in the path around the back of the tube throughout the entire portion of the tube where said applied electromotive force is applied to the tube, causing progressive, relative traversing movement of said tube and said zone of cross-seam current flow in a direction parallel to the seam, and progressively pressing the seam edges together.

FRANK L. SESSIONS.